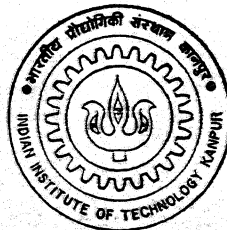


# COMPUTER AIDED DESIGN OF BUTTERFLY VALVE

by

SQN. LDR BRIJENDRA SINGH



DEPARTMENT OF MECHANICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY KANPUR

FEBRUARY, 1996

# **COMPUTER AIDED DESIGN OF BUTTERFLY VALVE**

*A Thesis Submitted*

*in Partial Fulfillment of the Requirements*

*for the Degree of*

**MASTER OF TECHNOLOGY**

*By*

**SQN. LDR BRIJENDRA SINGH**

*To the*

**DEPATRMENT OF MECHANICAL ENGINEERING**

**INDIAN INSTITUTE OF TECHNOLOGY**

**Feb ,1996**

27 MAR 1996  
CENTRAL LIBRARY  
I. I. T., KANPUR  

---

Acc. No. A. 121243

ME-1996-M-SIN-COM



A121243

## CERTIFICATE

29.2.96  
BSC

It is certified that the work contained in the thesis entitled "**Computer Aided Design Of Butterfly Valves**" by *Sqn Ldr. Brijendra Singh* has been carried out under my supervision and it has not been submitted elsewhere for a degree.



Dr. Birendra Sahay

Professor and Head of the Department  
Department of Mechanical Engineering  
IIT Kanpur

28 Feb, 1996

## **ACKNOWLEDGEMENTS**

*I would like to express my deep sense of appreciation and gratitude to my guide Dr. BIRENDRA SAHAY. His excellent guidance, motivation, encouragement and critical appreciation made my thesis work most enlightening and knowledgeable.*

*I also take this opportunity to put on record my indebtedness and sincere thanks to Dr. SANJAY G.DHANDE who introduced me to the field of COMPUTER AIDED DESIGN.*

*It is with pleasure that I thank Mr. Giresh Chaturvedi who has helped me sail through AUTOCAD drawings.*

*Finally, I would like to extend my thanks to all the members of CAD Project Laboratory for their co-operation and help and making my stay comfortable and enjoyable here at I.I.T.Kanpur.*

**BRIJENDRA SINGH**  
(Sqn.Ldr)

# TABLE OF CONTENTS

|   |          |
|---|----------|
| Certificate   | i        |
| Acknowledgements                                    | ii       |
| Table of contents                                   | iii      |
| List of figures                                     | iv       |
| List of Symbols                                     | vi       |
| Abstract  | ix       |
| <b>1. INTRODUCTION</b>                              | <b>1</b> |
| 1.1 History   | 1        |
| 1.2 Specific Problem Areas                          | 2        |
| 1.3 Globe Vs Rotary Valves                          | 3        |
| 1.4 Growth of High Performance Butterfly Valves     | 6        |
| 1.5 Problem Definition                              | 7        |
| 1.6 Literature Survey                               | 9        |
| 1.7 Objective                                       | 10       |
| <b>2. FLOW THROUGH BUTTERFLY VALVES</b>             |          |
| 2.1 Introduction                                    | 11       |
| 2.2 The Head Loss Factor                            | 14       |
| 2.3 Relation to Friction Flow                       | 14       |
| 2.4 Relation to $d_{EO}$ , $C_v$ , and $f$          | 15       |
| 2.5 Pressure Drop                                   | 16       |
| 2.6 Change in Diameter                              | 16       |
| <b>3. DESIGN METHODOLOGY FOR BUTTERFLY VALVES</b>   |          |
| 3.1 Sizing of Butterfly Valves                      | 24       |
| 3.1.1 Nomograph Technique                           | 27       |
| 3.2 Design Methodology for Parts of butterfly valve | 29       |
| 3.2.1 Calculation of Disc Thickness/Stress Analysis | 30       |
| 3.2.2 Body Wall Thickness                           | 33       |

|                   |  |    |
|-------------------|--|----|
| 3.2.3             | Calculation of Shaft Diameter/Offset Torque<br>Seat Torque/Bearing Torque/Offset Torque/Total Torque | 35 |
| 3.2.4             | Stress Calculation of Valve Shaft due to Combined<br>Bending and Torsion                             | 36 |
| 3.2.5             | Design of Shaft Bearing and Shaft Seals  | 38 |
| 3.2.6             | Design / Stress Analysis of Shaft Key  | 39 |
| 3.2.7             | Design / Stress analysis of Split Thrust Ring  | 41 |
| 3.2.8             | Design of locking Cap / Bolts for Locking Cap  | 41 |
| 3.2.9             | Stress Analysis of Valve Flange  | 43 |
| 3.2.10            | Stress Analysis for Shaft Flange   | 46 |
| 3.2.11            | Design of Cover for Body Non Driving End   | 49 |
| <b>4.</b>         | <b>DESIGN ALGORITHM AND TRIAL RUNS</b>   |    |
| 4.1               | Introduction   | 52 |
| 4.2               | Material Data Base   | 52 |
| 4.3               | Curve Fitting for Nomograph  | 56 |
| 4.3.1             | Nomograph ( fig 3.1 ) as a Polynomial Function   | 57 |
| 4.3.2             | Nomograph ( fig 3.2 ) as a Polynomial Function   | 58 |
| 4.4               | Calculation of K-factor for Pipes  | 59 |
| 4.5               | Adams Chart as Polynomial function   | 60 |
| 4.6               | Design Algorithms for Parts / Stress Analysis  | 65 |
| 4.7               | Illustrative Design and Trial Run  | 68 |
| 4.8               | Summary  | 72 |
| <b>5.</b>         | <b>CONCLUSIONS AND DIRECTION FOR FURTHER WORK</b>  |    |
| 5.1               | Conclusion   | 80 |
| 5.2               | Recommendation for further work  | 80 |
|                   | <b>REFERENCES</b>  | 81 |
| <b>APPENDIX A</b> | <b>Users Manual</b>  | 82 |
| <b>B</b>          | <b>Design Procedure and Package for implementation</b>   | 86 |
| <b>C</b>          | <b>Adams' Chart</b>  | 92 |

# LIST OF FIGURES

|             |   |    |
|-------------|---|----|
| Figure 1.1  | General purpose valves  | 4  |
| Figure 1.2  | Valve cost curve  | 5  |
| Figure 1.3  | Cross-sectional view of butterfly valve                                     | 8  |
| Figure 2.1  | Details of butterfly valve  | 12 |
| Figure 2.2  | Installation employing butterfly valve                                      | 13 |
| Figure 2.3  | Calculation of K-factor for change in section                               | 17 |
| Figure 2.4  | K-factor for sudden change in section                                       | 18 |
| Figure 2.5  | K-factor for gradual change in section                                      | 19 |
| Figure 2.6  | K-factor for bends of tube and hose   | 20 |
| Figure 2.7  | K-factor for entrance loss  | 21 |
| Figure 2.8  | K-factor for butterfly valve  | 22 |
| Figure 3.1  | Relation of flow through butterfly valve Vs Disc angle                      | 25 |
| Figure 3.2  | Relation of butterfly valve loss coefficient to disc angle                  | 26 |
| Figure 3.3  | Disc shape  | 32 |
| Figure 3.4  | Sectional view of body wall thickness                                       | 34 |
| Figure 3.5  | Sectional view of butterfly valve shaft and bearing                         | 37 |
| Figure 3.6  | Sectional view of shaft with key  | 40 |
| Figure 3.7  | Sectional view of split thrust ring   | 40 |
| Figure 3.8  | Sectional view of valve flange  | 45 |
| Figure 3.9  | Sectional view of shaft flange  | 48 |
| Figure 3.10 | Sectional view of cover at non driving end                                  | 50 |
| Figure 4.1  | Relation of shaft diameter to disc diameter<br>( Material-ST.ST.BS.970 )    | 61 |
| Figure 4.2  | Relation of shaft diameter to disc diameter.<br>( Material-AISI 316 / 304 ) | 62 |
| Figure 4.3  | Relationship of seat torque to valve disc diameter                          | 63 |



|             |  |    |
|-------------|--|----|
| Figure 4.4  | Moody chart                                | 64 |
| Figure 4.5  | Photograph of sectional view of shaft      | 73 |
| Figure 4.6  | Photograph of disc shape                   | 73 |
| Figure 4.7  | Photograph of wall thickness               | 74 |
| Figure 4.8  | Photograph of valve shaft                  | 74 |
| Figure 4.9  | Photograph of sunk key                     | 75 |
| Figure 4.10 | Photograph of bearing                      | 75 |
| Figure 4.11 | Photograph of split thrust ring            | 76 |
| Figure 4.12 | Photograph of locking cap for shaft        | 76 |
| Figure 4.13 | Photograph of valve flange stress analysis | 77 |
| Figure 4.14 | Photograph of disc angle Vs pressure drop  | 77 |
| Figure 4.15 | Photograph of bar chart                    | 78 |
| Figure 4.16 | Photograph of AUTOCAD drawing              | 78 |
| Figure 4.17 | Final drawing in AUTOCAD                   | 79 |

## LIST OF SYMBOLS

|                 |   |
|-----------------|---|
| a               | Moment arm ( mm )                                       |
| Ac              | Bolt area ( sq mm )                                     |
| b               | Width of key ( mm )                                     |
| d               | Valve shaft diameter ( mm )                             |
| da              | Flange outer diameter ( mm )                            |
| D               | Diameter of butterfly valve disc                        |
| d <sub>EO</sub> | Equivalent orifice diameter ( mm )                      |
| Da              | Body wall outer diameter ( mm )                         |
| dc              | Core diameter of bolt ( mm )                            |
| Di              | Body wall inner diameter ( mm )                         |
| d1              | Inner diameter of split thrust ring ( mm )              |
| d3              | Outer diameter of split thrust ring ( mm )              |
| di              | Flange inner diameter ( mm )                            |
| dt              | Bolt circle diameter (mm )                              |
| dL              | Pipe outer diameter (mm )                               |
| dD              | Diameter at the location of gasket load reaction ( mm ) |
| f               | Friction factor   |
| H <sub>L</sub>  | Head loss (mm)  |
| h <sub>F</sub>  | Flange thickness (mm )                                  |
| h <sub>A</sub>  | Length of flange through hub (mm )                      |
| K               | Head loss factor  |
| Kv              | Butterfly valve loss coefficient                        |
| Kr              | Bearing torque coefficient                              |
| L               | Length of key ( mm )                                    |
| Mb              | Bending moment (N-m )                                   |

|                  |   |
|------------------|---|
| $M_T$            | Twisting moment ( N-m )                                 |
| $M_v$            | Resultant moment ( N-m )                                |
| $n$              | Numbers of key  |
| $N$              | Numbers of bolt   |
| $P$              | Pressure (bar )   |
| $P_{RZ}$         | Additional pipe forces for unspecified conditions       |
| $R$              | Radius of curvature of disc (mm)                        |
| $S_r$            | Body wall thickness ( mm )                              |
| $S$              | Design factor of safety                                 |
| $S_F$            | Thickness of hub at the back of flange (mm)             |
| $t_l$            | Depth of shaft key (mm)                                 |
| $V$              | Average velocity through restrictions ( m / sec )       |
| $\mu$            | Coefficient of friction                                 |
| $\sigma_{zul}$   | Allowable design stress ( MPa)                          |
| $\sigma_{vorth}$ | Stress developed ( MPa)                                 |
| $\sigma_1$       | Calculated stress in flange through section A-A ( MPa ) |
| $\sigma_2$       | Calculated stress in flange through section B-B ( MPa ) |
| $\sigma_3$       | Calculated stress in flange through section C-C ( MPa ) |

## ABSTRACT

*In the present Work, a methodology for interactive design of BUTTERFLY VALVE has been developed. Based on the proposed methodology, a software package for interactive design has also been developed.*

*In this thesis, specific problem area encountered in the design of butterfly valves, and fluid mechanics for designing valve has been discussed .*

*The overall design procedure covers the design of major components of butterfly valve and then carry out stress analysis for safety of design. Extensive use of C-Graphics has been used to display sectional-view each component after design which makes the package more realistic. Finally the program draws the assembled view of all the designed components of the Butterfly valve. Here both I.S and B.S codes has been used for selection of materials for parts. The package can be use as an educational aid as well as by the Industries for the design of Butterfly valve.*

# CHAPTER-1

## INTRODUCTION

### 1.1 HISTORY

When man first used bamboo for pipelines, about 4000 years ago, a method to start and stop flow was first encountered, and the first plug valve was invented. This event was said to have taken place in China. Artifacts from the depth of mediterranean contained fragments of petcocks dating back to before the time of Christ. During the time of Roman empire, wooden valves were used that looked much like the valves manufactured today for use in wine casks and beer kegs.

Nearly every person in this civilized world now comes into contact with valves. They are the main controlling elements in the fluid-handling systems. Valves serve five primary functions.

1. To start and stop the flow.
2. To regulate and throttle the fluid flow.
3. To prevent back flow.
4. To regulate pressure.
5. To relieve excessive pressure.

How well these functions are accomplished largely determines the performance of the system.

Management is becoming more and more aware of the importance of valves in the industrial plants and processes. In the hydrocarbon and natural gas industries, valves represent about 10% of the new plant capital expenditures and 15% of the maintenance budget for replacement purchases.

Until the late 1950s, valve manufacturers generally kept pace with industrial and military demands. Space age technology then forced them to meet strange and unforeseen specifications. Fluid system control became a major problem in the design and development of missiles, advanced aircrafts, hypersonic testing facilities, and space vehicles. Enginneers were called on to design valves that could control extremely cold or hot, noxious, highly reactive, intractable,

self igniting fluid, valves that could operate at both high and low temperatures and pressures and high vibration levels, and could be lightweight and remotely operated.

## 1.2 Specific Problem Areas

Leakage of expensive, toxic, corrosive, or explosive fluids cannot be tolerated. Great effort is being expended to attain the nearly impossible goal of a zero leak valve.

The material selection problems facing industrial valve designer are extremely difficult. The following factors must be considered .

**Large temperature excursions :** The annealing effect of temperature cycling can change physical properties. Differential thermal expansion can cause warping and bending.

**Vacuum :** Many materials outgas in a vacuum environment and undergo property variations.

**Extreme temperatures :** Material loses strength at very high temperatures, and welding can occur. At low temperatures metals become brittle and sealing materials lose plasticity.

**Compatibility :** Some material, for example react with liquid oxygen when shocked. Metal parts may gall and experience excessive wear.

**Radiation :** Some nuclear valves must operate in high intensity radiation fields. The properties of polymeric materials can be greatly affected.

**Reliability:** It is often mandatory that valves operate perfectly for thousands of cycles at unattended industrial plants.

The problems enumerated encompass nearly every facet of valve design. The majority of problems, however, occur in three areas: extremely low and high temperatures, and reliability. The primary symptom of unreliability is leakage, which generally results from contamination in the system.

New materials, fresh design thinking, uncommon ingenuity are reflected in today's valves, actuators and positioners. The valve has made more progress in the last two decades than in any similar span of its 2000 years of development. The most apparent indication of genuine design advance is a graceful external appearance that "looks right", the typical modern valves make this point. Let's briefly review the conditions under which the valve lives.

Physical loads of valve come from line fluid and from adjoining pipes. Fluid pressure

range from high vacuum, causing light external load, to steady internal pressure of  $3.45 \times 10^7$  N/sq m or more. Fluid-transmitted shock and hammer can produce pressure spikes far in excess of nominal pressure maximum. Loads from adjoining piping can impose another serious threat to valve tightness and ease of operation.

Other enemies of valves include heat, cold, cavitation, corrosion, and erosion. Designer combat high temperature with appropriate alloys. Cavitation and erosion are two old foes that are being fought with increasing success today. Special disc materials and seat surface hardness can exceed 700 Brinell in today's valves. Stelliting is becoming more common for primary seating surfaces. Flow passage design continues to improve. It reduces erosion that has been a trouble source in many services, from feed water to hydraulic servo. Maintainability is better and still improving. Most of the new valve and actuator designs facilitate rapid inspection, repacking, regrounding and replacement. Control valves pioneered some of this improvement with quick-change trim.

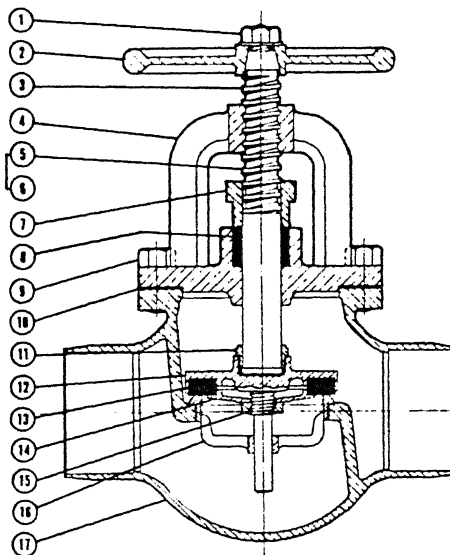
### **1. 3 GLOBE Vs ROTARY VALVES**

There has been a virtual revolution in the design and application of control valves. The once popular single seated and double seated valves have been displaced by top entry cage and flangeless rotary valves as the top choice in the field. The double seated valve, which only five years ago accounted for 50% share of the market, now account for less then 3% .

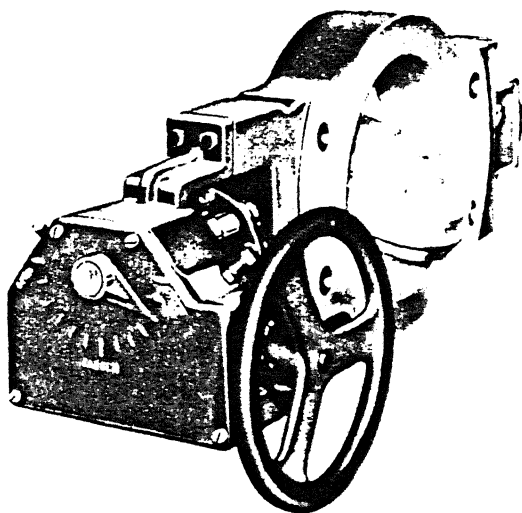
The modern cage valve has certain advantage such ease of maintenance, adaptability to low-noise trims, and better guiding. But the cage valve has the disadvantage of cost in the larger valve sizes. Figure 1.1 shows difference between globe and rotary valve, and figure 1.2 illustrates the cost advantage that the flangeless rotary valve (including butterfly valves) have over globe valves. Especially, in size above 100 mm rotary valves have the ability to offer tight shutoff with much less actuator power. They are small in size and lighter weight especially in size above 75 mm. There is clearly a size and weight advantage of a rotary valve over a globe valve for the same size valve.

Now, newer designs offer low-torque valves encapsulated actuators, backlash-free shaft connections, and eccentrically off-set disc with teflon seats for tight shut-off. The result is a dramatic upward shift in the market share enjoyed by a butterfly valves.

| PART                 |
|----------------------|
| 1. Handwheel Nut     |
| 2. Handwheel         |
| 3. Stem              |
| 4. Bonnet            |
| 5. Gland Nuts        |
| 6. Gland Studs       |
| 7. Gland             |
| 8. Packing           |
| 9. Hex Head Capscrew |
| 10. Body Gasket      |
| 11. Disc Holder Nut  |
| 12. Disc Holder      |
| 13. Disc             |
| 14. Disc Plate       |
| 15. Seat Disc Nut    |
| 16. Seat Ring        |
| 17. Body             |



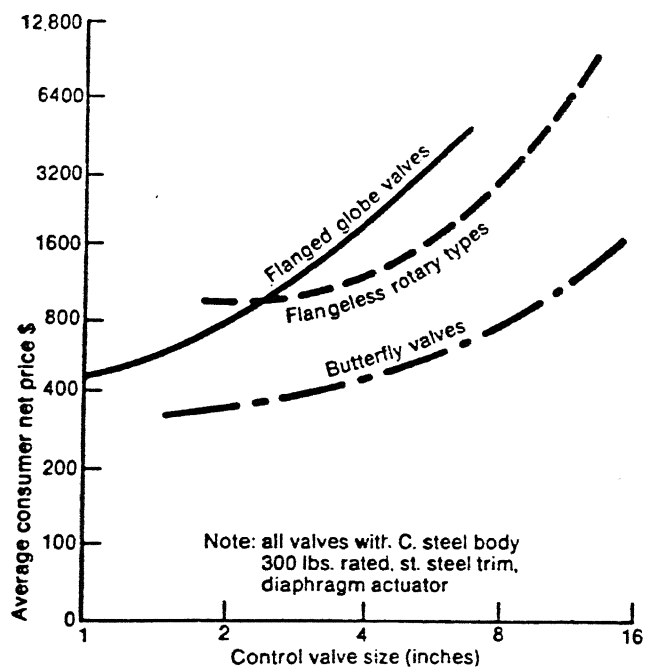
Globe-type valve with flat-face bolted bonnet.



*Courtesy of Continental Div. Fisher Controls Co.*

Handwheel-actuated butterfly valve.





**FIGURE 1.2** : Flangeless rotary valve, particularly Butterfly valves, Have a greater cost advantage over Globe Valves  
Reference[ 3 ].

## 1. 4 GROWTH OF HIGH PERFORMANCE BUTTERFLY VALVES

There have been several important changes in the application of valves by most industrial users. These developments includes the following.

1. Process systems have increased in size, pressure, and temperature.
2. The increased sophistication of production process combined with escalating labour costs have resulted in a growing need for more automated valve systems.
3. Increased legislation has forced users into tighter control of fluids to prevent leaks, spills, and fugitive emissions.
4. Energy costs have contributed to recycling of steam, water, and waste heat. This has increased the demand for leak-tightness of valve seats, gaskets, and packing.

The conventional metal-seated valves were found to be deficient for the following reasons:

1. **Cost** As the size of piping system increases, the size and cost of gate, globe, or plug valves tends to increase proportionally faster than line size.
2. **Sealing** A metal-seated valve cannot give completely reliable shutoff. Natural rubber can not be used in because it may deteriorate in time, particularly in contact with petrochemicals.
3. **Automation** Globe and gate valves require many revolutions of the handle or operator to open and close them. This makes them particularly a difficult and expensive to automate.
4. **Throttling** In the partially open position, most gate valves make a poor throttling device because of the chattering created across the valve discs. Globe valve tends to become very expensive as the line size increases, and plug valves have characteristically high torque, which contributes to poor control of the valve.

Over the past several years, there has been a significant change in the industrial valving requirements. A new generation of valves has been introduced based on the development of fluorocarbons such as teflon as a seat material and the acceptance of the butterfly-style body a process valve, a new concept has been developed - The high performance butterfly valve.

Now butterfly valves are being used from low pressure water service to applications in extremely sophisticated valving systems with very high temperature, high vacuum, low temperature applications, very high pressures.

To summarize, it can be said that the high performance butterfly valve market is the fastest changing segment of valve industry, growing at twice the rate of the total valve industry.

It is expected that in 5 years the unit sales will equal those of ball valve market, and that the majority of people now using plug, ball, and gate valves will be intimately familiar with high performance butterfly design.

## **1.5 PROBLEM DEFINITION**

The details of valve design can be divided into three individual design problems. Each phase or problem defined below can be treated separately .

1. The most important part of the valve is the flow control element. This is that portion of the valve, with its various components, which actually controls the flow of fluids through the valve.
2. Design of mechanism whereby the flow control elements may be adjusted to permit control of flow rate through the valve such as valve actuators, limit switch etc.
3. Isolation of the mechanism governing movement of the flow control elements from the fluid being handled in the valve i.e the sealing methods.

In the present work the first phase has been considered which consist of :

- a) Sizing of valve (i.e determining valve diameter for required maximum and minimum flow rate of fluid ).
- b) Designing major components of valve.
- c) Performing stress analysis of the valve components.
- d) Preparing final drawing and bills of material.

The design of Butterfly valve requires following specifications from the users.

1. Type of fluids to be handled.
2. Maximum differential pressure across the valve.
3. Maximum and minimum flow rate required.
4. Total head.
5. Type of entrance and exit of the flow.
6. Number and type of bends.
7. Length and type of pipe.
8. Valve flange specifications.
9. Shaft flange specifications.

Technical drawing of a pressure vessel head (circular) with a manhole on the left. The drawing includes two detail views:

- SEATING ARRGT**: A circular detail view showing the seating arrangement of the manhole flange. It includes labels 1 through 7.
- DETAILS AT I**: A circular detail view showing the details at the manhole flange, labeled I in the main drawing. It includes labels 8 through 15.

The main drawing includes labels 1 through 23, indicating various components and dimensions of the vessel head and manhole assembly.

| No | Description                    | Material                               | No | Description                  | Material                 |
|----|--------------------------------|--|----|------------------------------|--------------------------|
| 1  | Valve Body                     | C.I. IS 210 Gr FG260/300               | 12 | Flanged Bush                 | Bronze IS-318 Gr LTB-2.  |
| 2  | Body seat ring                 | St.St. BS 970 Gr 316 S 16              | 13 | Packing for Bush             | Graphited Asbestos       |
| 3  | Disc seal                      | Nitrile Rubber                         | 14 | Stub shaft                   | St.St. BS 970 Gr 431S29  |
| 4  | Disc                           | C.I. IS 210 Gr FG 260/300              | 15 | Dowel Pin                    | St.St. BS 970 Gr. 316S16 |
| 5  | Cover for Disc                 | C.I. IS 210 Gr FG 260/300              | 16 | Key for Drive shaft          | St.St. BS 970 Gr 316S16  |
| 6  | Clamping ring                  | MS IS 226 Gr Fe410S                    | 17 | Drive shaft                  | St.St. BS 970 Gr 431S29  |
| 7  | 'O' Ring for<br>Body Seat ring | Nitrile Rubber                         | 18 | Spacer D E                   | M.S.                     |
| 8  | Cover for body N D E           | MS IS 226 Gr. Fe410S                   | 19 | 'U' Cup Seal                 | Nitrile Rubber           |
| 9  | Spacer N D E                   | M.S.                                   | 20 | 'O' ring for 2               | Nitrile Rubber           |
| 10 | Gasket for Cover & Body        | CAF IS 2712 Gr C                       | 21 | 'U' Seal Retaining Bush      | Bronze IS-318, Gr. LTB 2 |
| 11 | Split Thrust Ring              | Aust-Iron IS 2749<br>Gr ASG-Ni-20 Cr-2 | 22 | Adaptor plate                | M.S. IS:226 Gr Fe410S    |
|    |                                |  | 23 | 'U' Seal Retaining<br>Washer | Bronze IS-318 Gr 2       |

**FIGURE 1.3** : Cross-sectional view of Butterfly valve.

All the above conditions are dependent on the requirements of users of the valve. The sizing of valve ( i.e determining valve diameter to meet required flow rate) is done by Nomograph technique described later. It involves a number of manual iterations, look up charts etc.

Design of major components of valve and its stress analysis is done by manual calculations. The design methodology of parts is discussed in chapter 3. Following are the parts which are designed step by step. The cross sectional view of the valve is shown in figure 1.3.  
**DISC :** This is the main flow controlling element, which rotates on either vertical or horizontal axis. When the disc lies horizontally, the valve is fully open, and when the disc approaches the vertical position, the valve is shut off. Intermediate position of disc is used for throttling purposes.

**WALL BODY:** This is the outer body of the valve which houses the disc, shaft, bearing etc. It is generally made of cast iron.

**SHAFT:** The disc is mounted on the shaft and total torque is transmitted to the gear box through it.

**BEARING:** The bearing is of journal type with bronze lining. It is designed to withstand full differential pressure on disc.

**KEY:** The key used is rectangular sunk key for torque transmission between the disc and the shaft.

**SPLIT THRUST RING :** This is used at the non-driving end of shaft to prevent axial movement.

**COVER FOR NON DRIVING END.**

**LOCKING CAP:** It is used to keep the disc in fully open or close position in the event of necessity to remove gear box for repair.

**BOLTS FOR LOCKING CAP**

**VALVE SHAFT FLANGE ANALYSIS**

**SHAFT FLANGE STRESS ANALYSIS**

## **1. 6 LITERATURE SURVEY**

The **NOMOGRAPH TECHNIQUE** for sizing butterfly valve was first published in [9]. The same has been improved and was made available in [3] from where it has been adopted. The various parts of butterfly valve such as disc, shaft, key, bearing, split ring etc have standard

design procedure and different text books [1,2,3,6,7,12,13,14,15,16] have been referred for design. Every country has its own standardization scheme. Standard data for mechanical components has been referred from ASME (American society of mechanical engineers ), B S (British standard ) code, I.S.I (Indian Standards Institution ) code. General methods for calculating torque values, ADAMS CHARTS (attached as appendix C ) for seat torque and shaft diameters for various valve size was made available from [ 8], a leading manufacture in butterfly valves.

Using many of the above sources, a consolidated approach for the design and analysis of butterfly valves has been developed in this thesis. A computer aided design approach facilitates in automatically generating the basic design of the valve components and its assembly. It will help the designer in iteratively changing the parameters and arriving at a satisfactory design in a shorter time. It is hoped that methodology given here will of help to the manufacturing industries.

## **1. 7 OBJECTIVE**

With the acceptance of butterfly valve in the process control and with the market growing at twice the rate of total valve industry, a need to develop a computer aided design of butterfly valve was felt necessary since the manual designing methods take enormous time (about 500-700 man hours)and any modification or iteration delays the process further.

Keeping in view the above mentioned point, it was felt that an interactive package for the design of all the major components of butterfly valve will significantly enhance the designing capabilities of a designer.

A interactive computer program has also been developed for the Sizing of butterfly valve and design of all the major components of valve using Indian Standards code, B.S specifications and also to carry out stress analysis of components for safety of design, Finally to prepare bills of material and to assemble all the designed component to produce final scale drawing of the valve.

## CHAPTER-2

# FLOW THROUGH BUTTERFLY VALVES

### 2.1 INTRODUCTION

The use of a butterfly valve as a final control element is basically associated with a flow control problem, when the object is to maintain

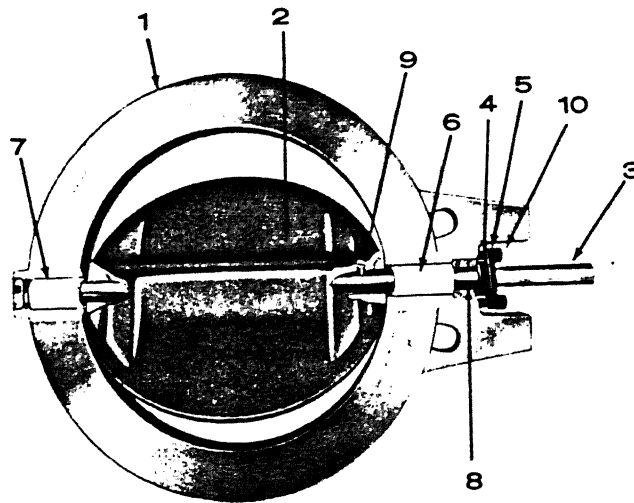
- a) Fixed flow rate ( flow rate control ).
- b) Desired line pressure( Line pressure control ) .

Figure 2.1 shows details of a typical butterfly valve. The control valve is used as a variable restriction (analogous to variable resistance) to add loss in the system and to establish a energy balance required to produce the desired result. Consider a common example of a valve being used to control flow in connecting pipeline between two ground sources (figure 2.2). The following factors enter into the problem:

1. Total head or potential energy of the system i.e the difference in hydraulic elevation between the water surfaces of reservoirs.
2. Entrance loss as the water leaves reservoirs A and enters the pipeline.
3. Pipe and fitting losses in the line from reservoir A to reservoir B.
4. Exit loss as the water leaves the pipeline and enters reservoir B.

Limitation on total system losses, that is, for a specific flow rate, the total of all system losses (entrance loss at A + pipes & fittings losses + exit loss at B ) at that rate must not be greater than the total head or the potential energy available. Any excess of total head (Total head - Head losses in system ) available over the system losses for the desired flow rate must be dissipated across the control valve. If the flow rate is changed, the system losses will change and the head to be dissipated across the valve has to change correspondingly.

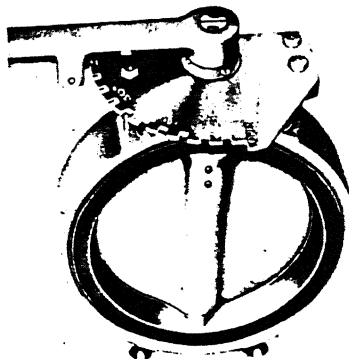
Entrance and exit losses, pipe and fitting losses, the total head and the types and number of fittings in the line must be known in order to calculate how much energy dissipation (head loss or K factor) is required from the valve.



- |                  |                 |
|------------------|-----------------|
| 1—Body           | 6—Upper bearing |
| 2—Disc           | 7—Lower bearing |
| 3—Shaft          | 8—Packing       |
| 4—Gland          | 9—Pin           |
| 5—Gland retainer | 10—Gland screws |

*Courtesy of Rockwell Mfg.*

Identification of butterfly valve parts.

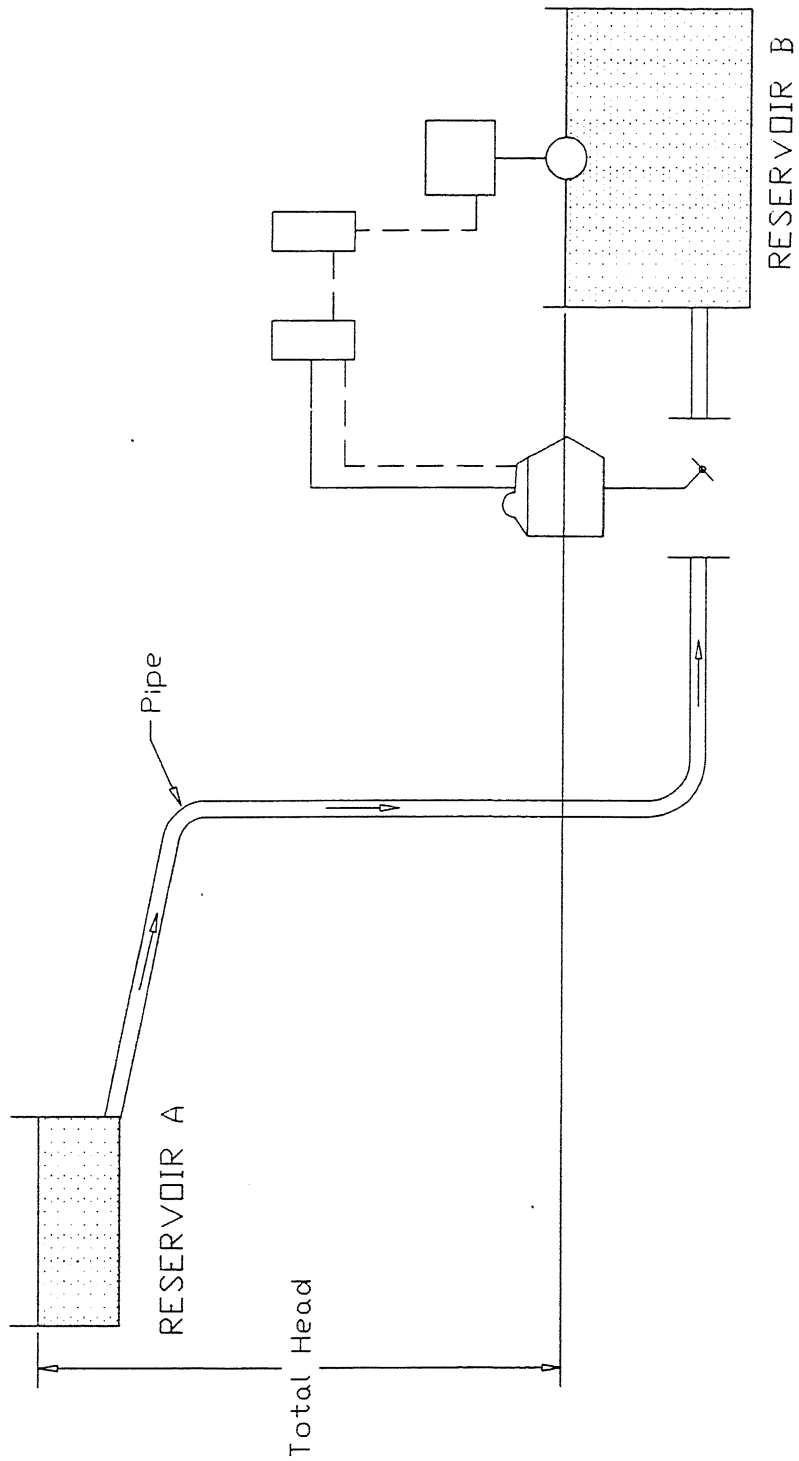


*Courtesy of Continental Div. Fisher Controls Co.*

Lever-actuated butterfly valve.

**FIGURE 2.1** Details of Butterfly valve.





**FIGURE 2.2** Installation employing Butterfly valve for flow control between two ground sources.

The purpose of this chapter is to outline methods for computing pressure drops and hence flow calculation for any type of loss inducer, with particular emphasis on valve sizing. This chapter also present in a convenient format some head loss factor ( K ) data currently scattered widely through the literature[1,2,3,4,13,14] and to review some background informations on the head loss factor (K) .

## 2.2 THE HEAD LOSS FACTOR (K-FACTOR)

The K or head loss factor is defined by

$$H_L = K \frac{V^2}{2g} \quad (2.1)$$

The Head loss factor (K) is a measure of the energy (pressure) loss of a fluid passing through a restriction. The velocity to be used in equation (2.1) is taken by convention to be the average velocity through the restriction, which from the continuity equation is a measure of the fluid flow through the restriction .

The Head loss factor (K) is often strongly dependent on Reynolds number and also varies with surface finish in the piping systems and with the geometrical factors, particularly pipe or restriction diameter. It cannot be used in laminar flow regime, since the head loss does not depend on the square of the velocity.

## 2.3 RELATION TO FRICTION FLOW

The surface finish of flow passage will affect the loss of energy of a flowing fluid. This loss is described in terms of a friction factor, which depends on the surface roughness and the flow area or diameter:

$$f = F(\epsilon, d) \quad (2.2)$$

Where f is the friction factor .

$$K = f \frac{L}{d_L} \quad (2.3)$$

The Head loss factor (K) for a pipe or other fluid conduit depends on this friction factor

$$K = f \left( \frac{L}{d_L} \right) (\text{equivalent}) \quad (2.4)$$

and on the pipe geometry, specifically the length ( L ) and inside diameter (  $d_L$  ).

In cases other than straight pipe it is often convenient to express the loss as of an equivalent amount of straight pipe of the same diameter. For example, an elbow may have the same loss factor as 30 diameters length of straight pipe [3].

The friction factor term must be added in to obtain the total Head loss factor (K). Often, however, this term is negligible small compared to other losses and may be ignored.

#### 2.4 RELATION TO $d_{EO}$ , $C_v$ , AND $f$

In some problem for valve sizing an equivalent sharp edge orifice may be known. In all these relationships  $d_L$  is the inlet diameter to the valve or component and  $b_1$ ,  $b_2$  is constant coefficient,  $d_{EO}$  is the equivalent orifice diameter. In this case, the total Head loss factor or K-Factor may be found from

$$K = b_1 \left( \frac{d_L}{d_{EO}} \right)^4 \quad (2.5)$$

or, conversely, if a total Head loss factor (K) is known, this equation will give the equivalent sharp edge orifice diameter. Similarly, if the valve flow coefficient is known, the total Head loss factor (K) may be found from

$$K = b_2 \frac{d_L^4}{C_v^2} \quad (2.6)$$

The basic problem in valve designing is to properly size the valve to pass a required flow usually with specified pressure drop. Head loss factor (K) analysis provides one way of determining whether or not a specified valve of given size will meet the requirements. From

knowledge of its Head loss factor (K) and pressure drop, an equivalent orifice or valve coefficient can be calculated and used to compute the expected flow.

## 2.5 PRESSURE DROP

Once the total head loss factor (K) is known from the above three equations or from summing head loss factors or K-factors for individual restrictions, it may be used in Darcy's equation:

$$\Delta P \propto \frac{\rho q^2 (K_{total})}{d_L^4} \quad (2.7)$$

to find the pressure drop through the components or series of restrictions under consideration.

In many problems of valve design it is desirable to have as low a pressure drop through the valve as possible consistent with the flow requirements. In such cases it is generally desirable to keep the effective flow area between 100 and 120 % of the inlet area [3] because this will result in lowest pressure drop. When a lower pressure drop is required than that obtained, the restrictions with the largest head loss factor may be modified to result in a lower overall K-factor and pressure drop.

## 2.6 CHANGE IN DIAMETER

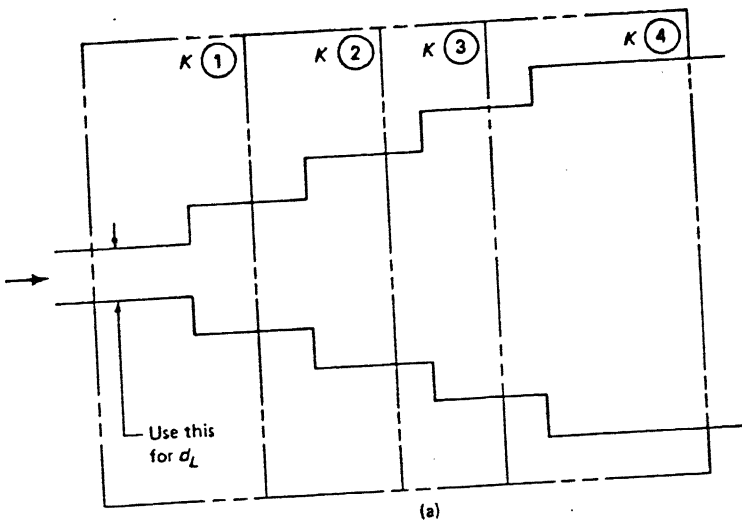
In the previous paragraphs it was assumed that the flow diameter never decreases below that of inlet diameter. In those instances the Head loss factor (K) for the various restrictions may be summed to give a total K-factor, which then can be used to find the pressure drop. (fig 2.3 a). In case where a diameter becomes less than the inlet diameter (figure 2.3 b), a new procedure is required. For such problems, the following method is used [3].

The system is partitioned into sections such that for each section the K-factor may be found. Proceeding from the inlet to the outlet, sum all the K-factor for which the diameter is equal or exceeds the inlet diameter and find the pressure drop to this point. For a diameter less than inlet diameter, the head loss factor (K) is found from that sections to the next one with diameter less than its diameter and pressure drop is computed. At the end sum all the pressure drop to give a total pressure drop for the system."

Thus, equation (2.7) or an equivalent will be used repeatedly, once for each region up to

Use  $K$  total.

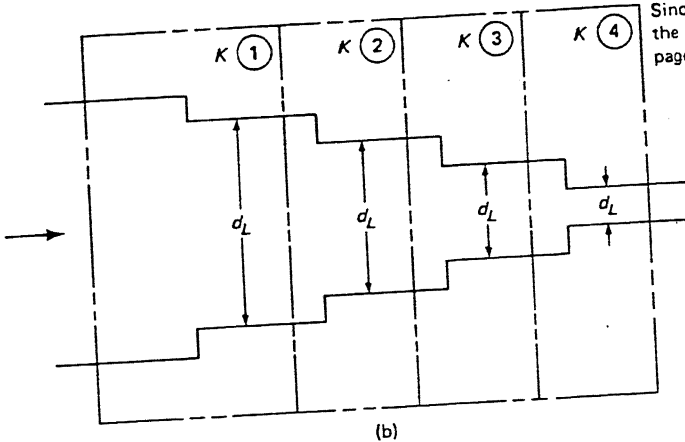
$$\begin{aligned}
 &+ K_1 \\
 &+ K_2 \\
 &+ K_3 \\
 &+ K_4 \\
 &\hline
 &= K_{\text{total}} \\
 &\approx \Delta P_{\text{total}}
 \end{aligned}$$



(a)

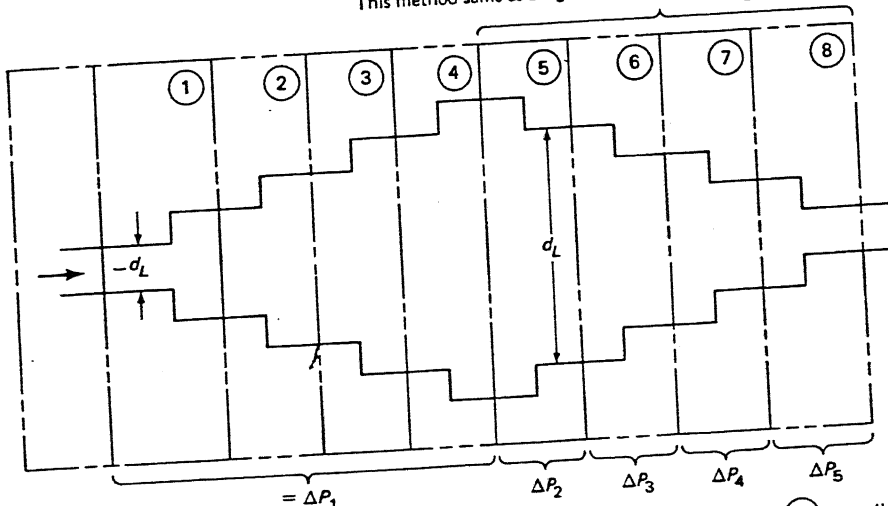
Since  $K$  is determined by  $a/A$  then  $d_L$  always = the smallest restriction (see changes in section) page 155

$$\begin{aligned}
 K_1 &\approx \Delta P_1 \\
 K_2 &\approx \Delta P_2 \\
 K_3 &\approx \Delta P_3 \\
 K_4 &\approx \Delta P_4 \\
 \hline
 &\approx \Delta P_{\text{total}}
 \end{aligned}$$



(b)

This method same as b fig. except when  $d_L$  @ (5) is larger than  $d_L$  @ (1).

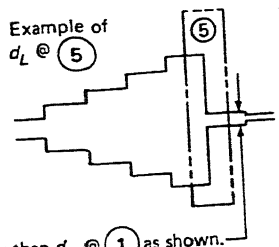


$$\sum_i K_{\text{total}} = \Delta P_1$$

(c)

$$\begin{aligned}
 \Delta P_1 &\approx K_1 \text{ thru } K_4 \\
 \Delta P_2 &\approx K_5 \\
 \Delta P_3 &\approx K_6 \\
 \Delta P_4 &\approx K_7 \\
 \Delta P_5 &\approx K_8 \\
 \hline
 &= \Delta P_{\text{total}}
 \end{aligned}$$

Example of  $d_L$  @ (5)



Use this approach when  $d_L$  @ (5) is smaller than  $d_L$  @ (1) as shown.

FIGURE 2.3 Calculation of K-factor for change in diameter.

# Sudden changes in section

|       |      |      |      |      |      |      |      |      |       |
|-------|------|------|------|------|------|------|------|------|-------|
| K     | 0.81 | 0.64 | 0.49 | 0.36 | 0.25 | 0.16 | 0.09 | 0.04 | 0.01  |
| $a/A$ | 0.1  | 0.2  | 0.3  | 0.4  | 0.5  | 0.6  | 0.7  | 0.8  | 0.9   |
| K     | 0.4  | 0.38 | 0.34 | 0.30 | 0.24 | 0.18 | 0.1  | 0.05 | 0.015 |

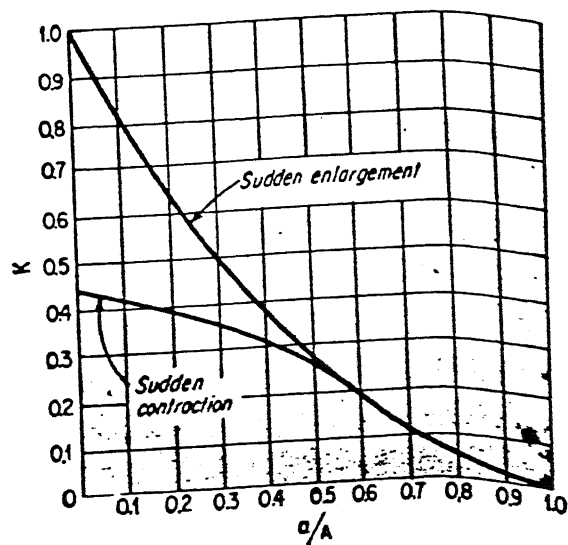
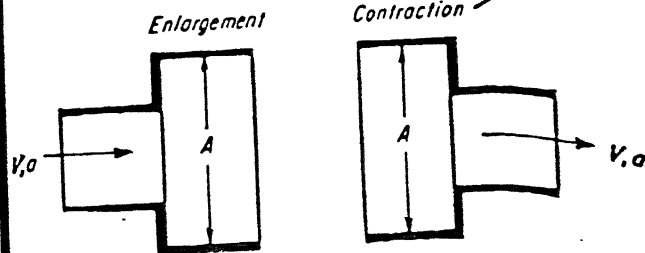


FIGURE 2.4 K-factor for sudden change in section.

# Gradual changes in section

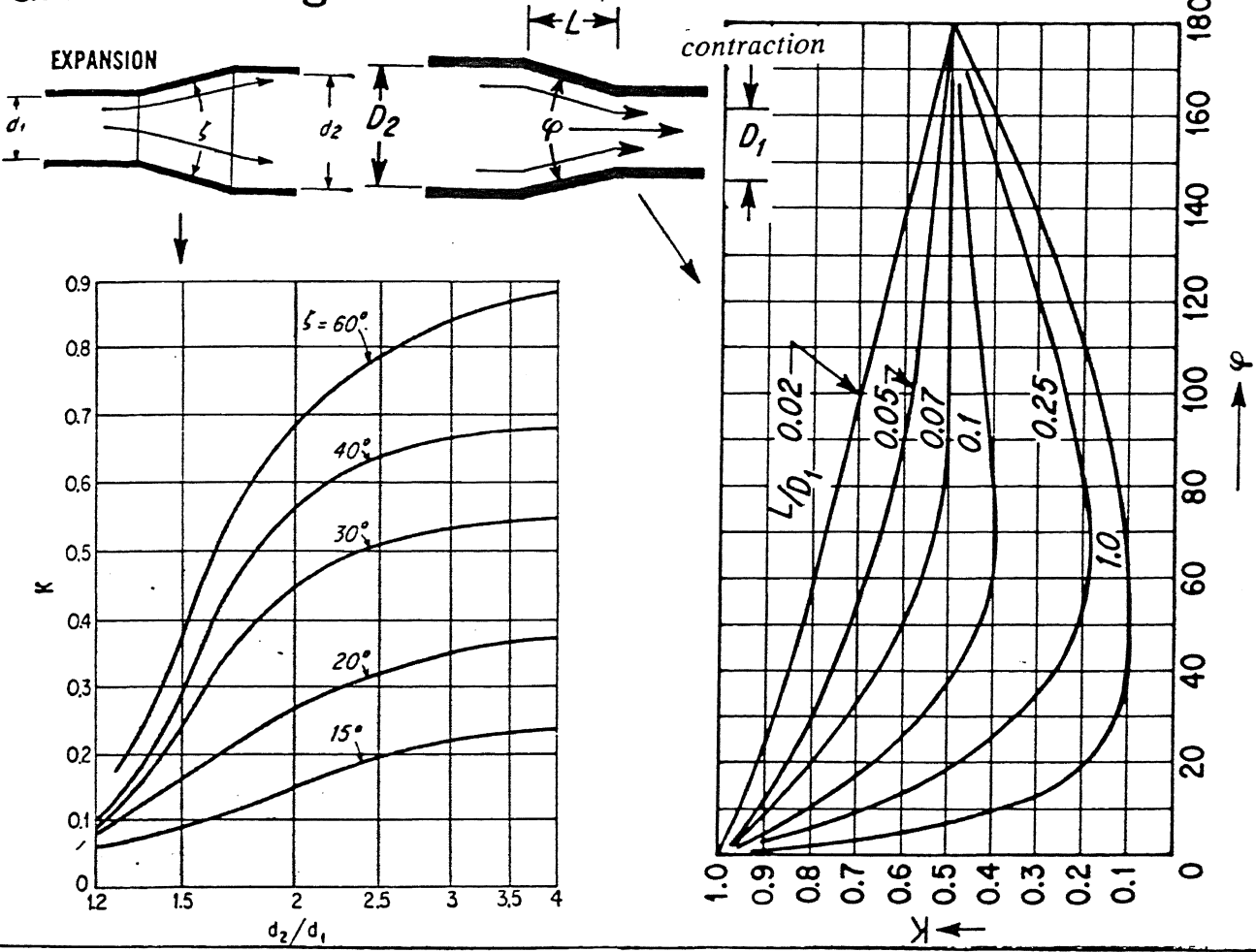
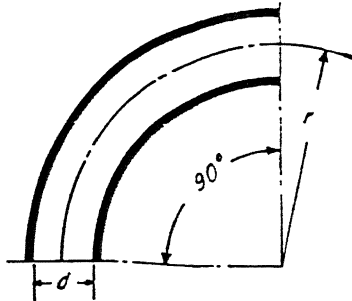
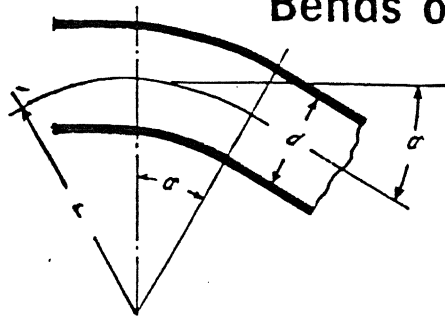


FIGURE 2.5 K- factor for Gradual change in section.

## Bends of tubing and hose



Best  $K = 0.1$  to  $0.15$  for smooth  $90^\circ$ -bend, and  $r/d$  at ideal 2 to 4

If bend is angular (or smooth with  $r/d < 1$  or  $> 6$ ) use this table for  $K$ : (conservative)

| $\alpha$ | 10   | 20  | 30   | 40   | 50  | 60   | 70   | 80   | 90   |
|----------|------|-----|------|------|-----|------|------|------|------|
| $K$      | 0.04 | 0.1 | 0.17 | 0.27 | 0.4 | 0.55 | 0.70 | 0.90 | 1.12 |

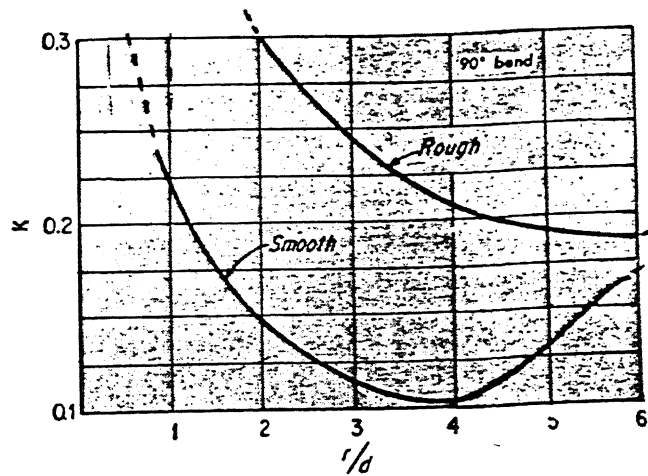


FIGURE 2.6 K-factor for bends of tubing and hose.



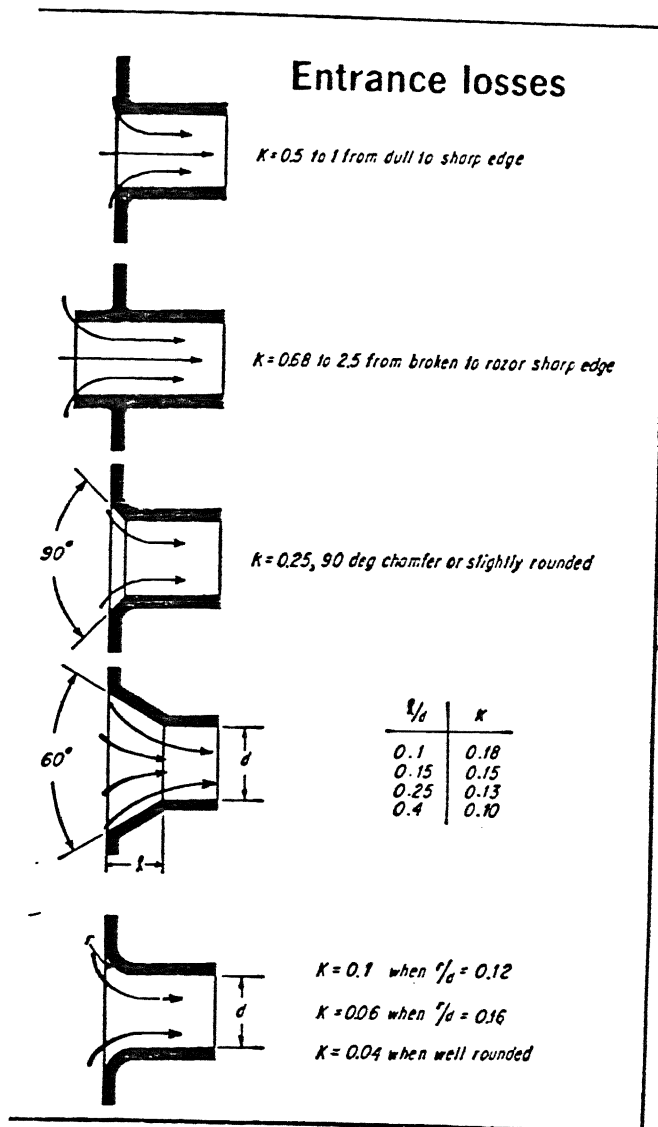


FIGURE 2.7 K-factor for entrance loss.

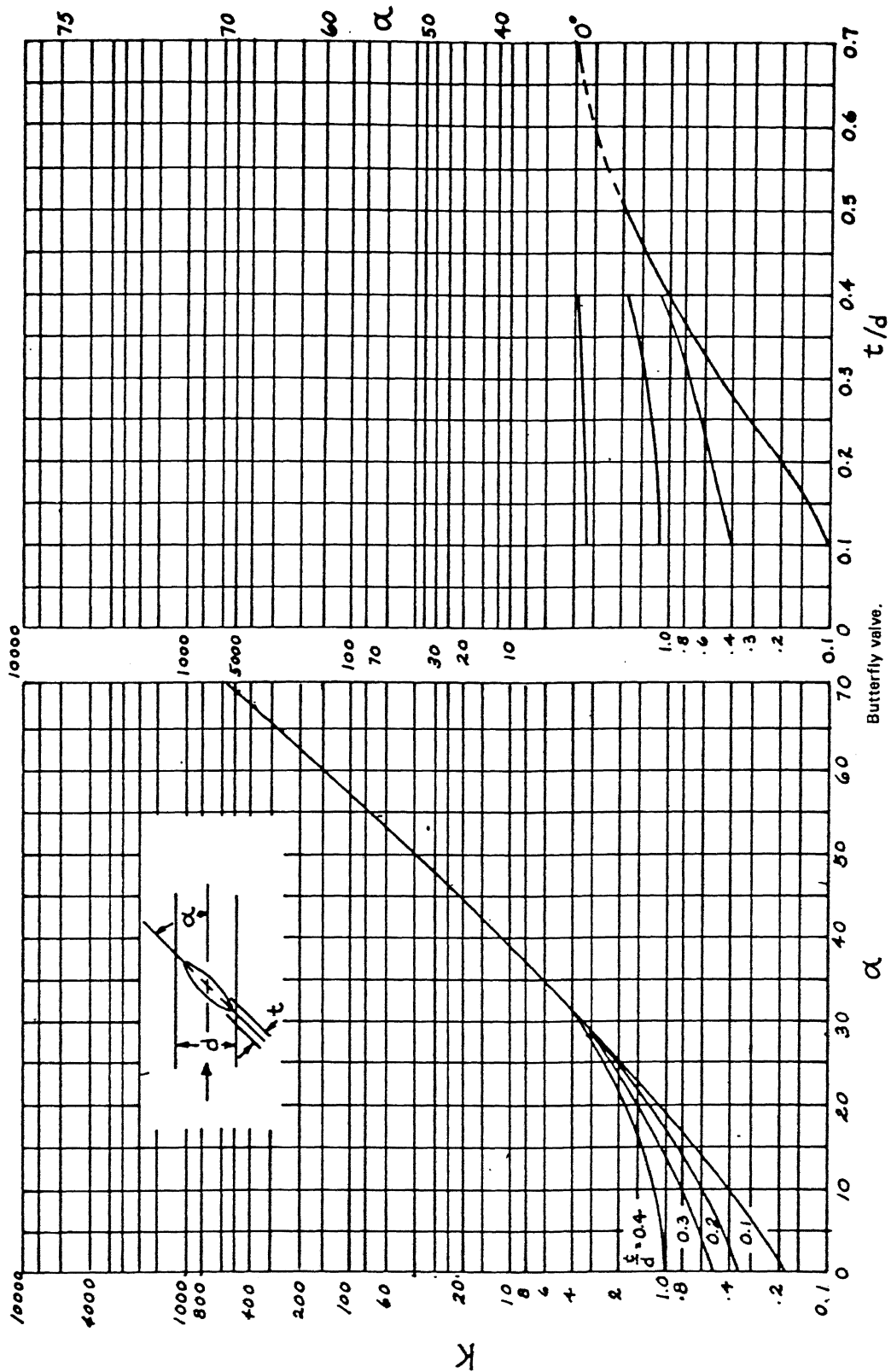


FIGURE 2.8 K-factor for butterfly valve for various disc positions.

a point where the flow diameter decreases to less than the inlet diameter, and these results will be summed up to give the total pressure drop:

$$\Delta P_{total} = \Sigma \Delta P_i \quad (2.8)$$

where

$$\Delta P_i \approx (\Sigma K_j)_i \quad (2.9)$$

The following is the K-factor information found widely scattered in the literature [1,2,3,4,13,14] which has been assembled here in a convenient format for use by valve designers and others.

**SUDDEN CHANGE IN SECTION:** Figure 2.4 shows K-factor for sudden expansion or contractions. For either case the velocity to be used in eq.(2.1) corresponding to the velocity in smaller diameter section.

**GRADUAL CHANGE IN SECTION :** Figure 2.5 presents the K-factor for gradual expansion and gradual contraction respectively.

**SMOOTH BENDS :** Figure 2.6 shows K-factors for smooth 90-degrees bends and correction factor for other angles.

**ENTRANCE LOSSES:** The K-factors for several entrance configurations are shown in figure 2.7

**EXIT LOSS :** The K-factor for any exit loss regardless of the exit configuration is 1.0. This follows from the conservation of energy principle.

**BUTTERFLY VALVE:** Figure 2.8 give K-factor for butterfly valve as a function of amount of opening. Valves may differ from one manufacturer to another.

## CHAPTER-3

# DESIGN METHODOLOGY FOR BUTTERFLY VALVES

### 3.1 SIZING OF BUTTERFLY VALVES

Sizing of a butterfly valves basically means determining the diameter of the valve disc to adjust between the required maximum and minimum flow rate. The following information is needed for the sizing of butterfly valves.

- a) Maximum flow rate required.
- b) Minimum flow rate required.
- c) Total head or potential energy of the system.
- d) Head loss in the system.

The head loss factor or K-factor (energy loss of fluid passing through restriction ) of the system is determined as described in Chapter-2. Then the NOMOGRAPH TECHNIQUES for sizing the butterfly valve for best control operation is used. All applications should be checked for cavitation.

With reference to figure No-3.1, for  $K=16$ , it may be noticed that for a disc position of 60 degrees there are relatively small changes in flow for increasing angular travel of disc. A similar situation exists below 15 degrees disc position.

Operation of a valve in the ranges beyond these extreme disc positions tends to produce "mushy" wandering control. Therefore, it is recommended that the butterfly valve be so chosen to operate between angles which are best for the system conditions. This frequently, but not always results in a valve smaller in size. Also each system will have its own head loss factor or K-factor value. Consequently, each system will have its own optimum disc angle.

The rule of thumb that the valve should be sized to have a maximum velocity of approximately 16 ft/sec(4.5 m/sec) is still valid for rough checking. Valve velocity means the velocity through a pipe of the same nominal size of valve.

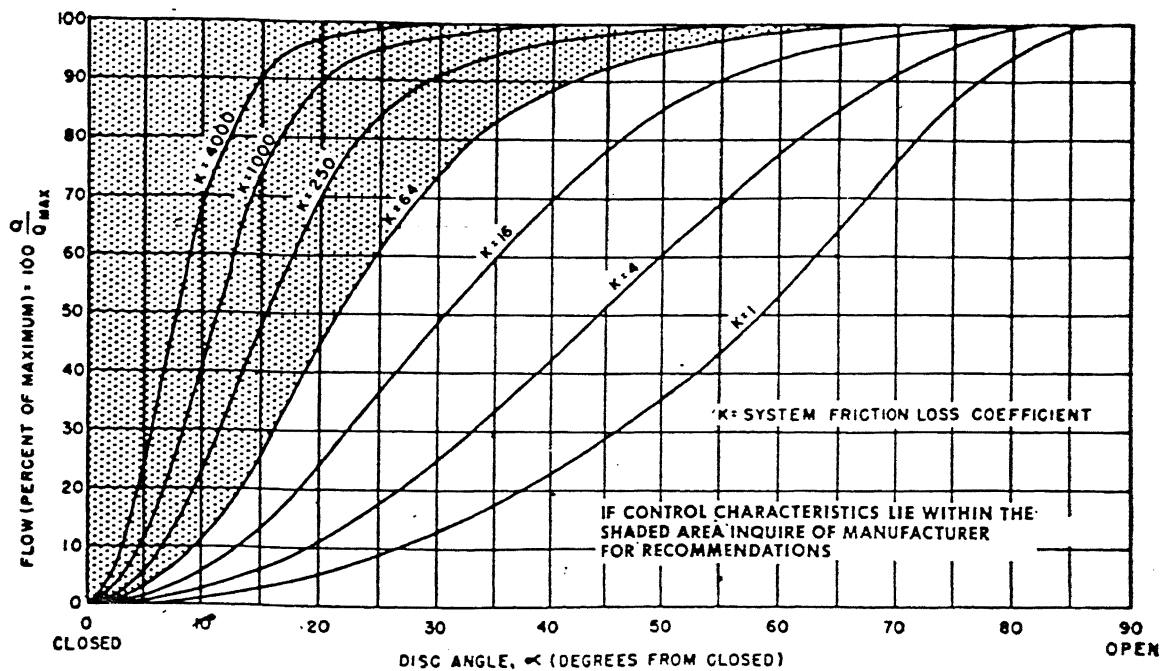


FIGURE 3.1 Relation of flow through butterfly valve Vs disc angle.

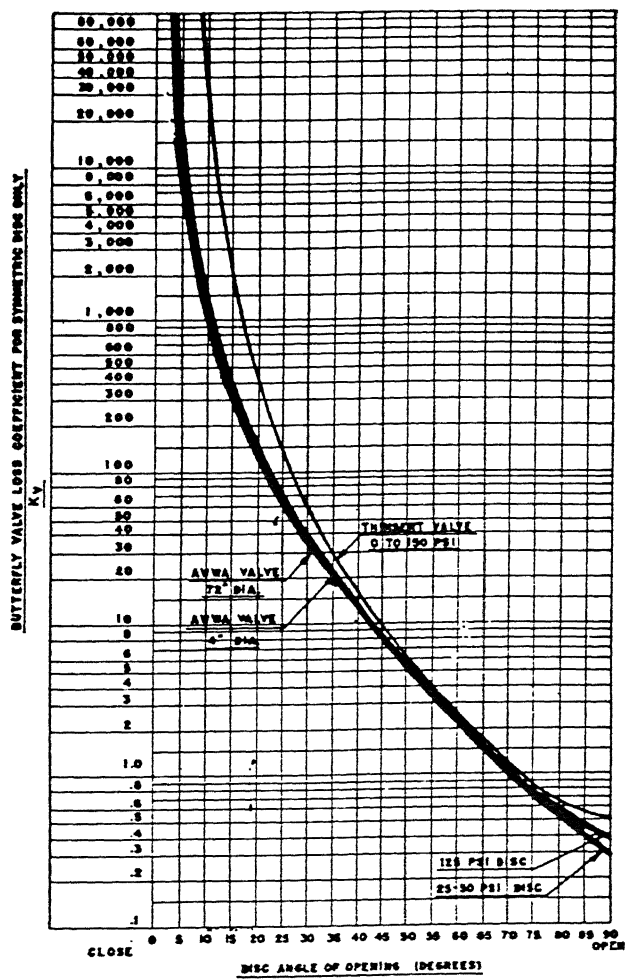


FIGURE 3.2 Relation of butterfly valve loss coefficient to disc angle of opening in degrees.

The nomograph method for sizing of butterfly valve is described below.

### 3.1.1 NOMOGRAPH TECHNIQUE

The nomograph technique utilizes figures 3.1 & 3.2 . A specific solution of valve size may be worked out using following data:

Step 1.

Diameter of pipeline=1000 mm

Maximum velocity = 2.13 m/sec

minimum velocity = 0.3657 m/sec

Total head (51.8 - 42.67 ) = 9.13 m

Find System Loss coefficient "Ks"

|                           |        |
|---------------------------|--------|
| Entrance Loss(sharp edge) | K=0.50 |
|---------------------------|--------|

|                       |        |
|-----------------------|--------|
| Exit Loss(sharp edge) | K=1.00 |
|-----------------------|--------|

|   |        |
|---|--------|
| For two 80 mm elbow loss(long sweep)<br>(when L/D=20), $0.023 \cdot 20 \cdot 2$ | K=0.92 |
|---|--------|

|  |         |
|--|---------|
| Riveted steel pipe( $f \cdot L/D$ )<br>(when L/D=500), $0.023 \cdot 500$ | K=11.50 |
|--|---------|

---

|                               |          |
|-------------------------------|----------|
| Total System loss coefficient | Ks=13.92 |
|-------------------------------|----------|

A curve for Ks=13.92, on figure 3.1 would fall between k=4 and k=16, with optimum control angles from 15 degrees to 65 degrees.

Step 2

Find 1000 mm valve loss(Kv) and opening angles.

Calculate total system Kt, required to dissipate 9.13 m of differential head.

#### a) FOR MAXIMUM FLOW

|   |        |
|---|--------|
| $K_t = \Delta H \cdot 2 \cdot g / V^2 \text{ max} = 9.13 \cdot 2 \cdot 9.82 / (2.13)^2$ | =39.48 |
|---|--------|

|                                   |        |
|-----------------------------------|--------|
| $K_v = K_t - K_s = 39.48 - 13.92$ | =25.56 |
|-----------------------------------|--------|

Determine valve open angle from figure 3.2

$\alpha \text{ max} = 33 \text{ degrees.}$

This is an acceptable disc position.

### b) FOR MINIMUM FLOW

$$K_t \min = \Delta^2 \cdot g / V \max = 9.13^2 \cdot 9.81 / (0.3657)^2 = 1339.42$$

Required valve loss:

$$K_v \min = K_t - K_s = 1339.42 - 13.92 = 1325.5$$

$\alpha \min = 9$  degrees .

This is much less than the recommended 15 degrees.

The 1000 mm valve in this case is not the most satisfactory selection. trying smaller size valve say 600 mm valve size.

The  $K_s = 13.92$  of 1000 mm valve will change as follow:

$$1000 \text{ mm pipe loss (from step 1)} \quad K_s = 13.92$$

1000 mm to 600 mm gradual contraction ( negligible)

$$600 \text{ mm to } 1000 \text{ mm gradual enlargement (with total angle of } 20 \text{ deg )} \quad K = 0.25$$

Total system loss

---

14.17

Step 3.

Find for 600 mm valve loss  $K_v$  and opening angle

### a) FOR MAXIMUM FLOW RATE

Required valve loss  $K_v =$

$$(K_t - K_s) (600/1000)^4 = (39.42 - 14.17) (600/1000)^4 = 3.2724$$

Valve open angle max = 52.5 degrees

This is an acceptable position

### b) FOR MINIMUM FLOW RATE

Require valve loss  $K_v \min =$

$$(K_t - K_s) (600/1000) = (1339.42 - 14.17) (600/1000)^4 = 171.75$$

Valve open angle minimum = 15.5 degrees

This is an acceptable disc position.

The 600 mm valve size would be the most satisfactory selection.



### **3.2 DESIGN METHODOLOGY FOR THE PARTS OF BUTTERFLY VALVE**

In the following sections, design methodology for the parts of butterfly valve is given. The design algorithms along with trial runs is given in chapter 4.

1. a) Valve disc thickness and shape design.  
b) Stress analysis of disc.
2. Wall body thickness design.
3. a) Calculation of shaft diameter and total torque acting on it.  
b) Stress analysis of shaft for combined bending and torsion.
4. Journal bearing design
5. a) Keys for torque transmission.  
b) Stress analysis of key.
6. a) Split thrust ring design.  
b) Stress analysis of split thrust ring.
7. Cover for non driving end.
8. a) Locking cap design.  
b) Bolts for locking cap.
9. Valve flange stress analysis.
10. Shaft flange stress analysis.

### 3.2.1 CALCULATION OF DISC THICKNESS/SHAPE/STRESS ANALYSIS

The disc is assumed to be a circular plate, Uniformly distributed load, at full-y closed position ,and supported at two diametral end by shafts.

The following inputs are required for design of disc.

- a) Material for disc.
- b) Design factor of safety.

The disc thickness and deflection is calculated from standard formulas of theory of plates.

With reference to figure No-3.3

$$W = P * 0.5 * \pi * D^2. \quad (3.1)$$

$$\text{Thickness} = \sqrt{\frac{k1 * w}{s}} * 10.$$

*Maximum deflection at mid point of circular edge.*

$$y = \frac{k2 * w * (0.5 * D)^2}{E * t^3}$$

Once the thickness of disc is calculated from above formula (3.1) the shape determination and stress analysis of disc is done as follows

Reference is made to figure 3.3 for stress analysis of disc of lens shape .

$$R = 0.9 * D \quad (3.2)$$

$$E = 0.15 * R$$

$$C = 0.75 * D$$

$$S_s = \frac{H}{1.5}$$

continued :-

$$\alpha = 2 \cdot \arccos \left( \frac{F + \frac{H}{2}}{R} \right)$$

$$\beta = 2 \cdot \arccos \left( \frac{F + \frac{H}{2}}{R + Ss} \right)$$

$$A = 2 \cdot R \cdot \sin \left( \frac{\alpha}{2} \right)$$

$$K = 2 \cdot (R + Ss) \sin \left( \frac{\beta}{2} \right)$$

$$\begin{aligned} I_x = & \frac{(D-C) \cdot H^3}{12} + 2 \cdot \left[ \frac{(R+Ss)^4}{8} \left( \pi \cdot \frac{\beta}{180} - 0.5 \cdot \sin(2 \cdot \beta) \right) \right] \\ & - 2 \cdot \frac{K^6}{12^2 \left[ \frac{(R+Ss)^2}{2} \left( \pi \cdot \frac{\beta}{180} - \sin \beta \right) \right]} \\ & + 2 \cdot \left[ \frac{(R+Ss)^2}{2} \left( \pi \cdot \frac{\beta}{180} - \sin \beta \right) \right] \cdot \left( \frac{K^3}{12 \cdot \left[ \frac{(R+Ss)^2}{2} \cdot \left( \pi \cdot \frac{\beta}{180} - \sin \beta \right) \right]} - F \right)^2 \\ & - 2 \cdot \left[ \frac{R^4}{8} \left( \pi \cdot \frac{\alpha}{180} - 0.5 \cdot \sin(2 \cdot \alpha) \right) \right] + 2 \cdot \frac{A^6}{12^2 \left[ \frac{R^2}{2} \left( \pi \cdot \frac{\alpha}{180} - \sin \alpha \right) \right]} \\ & - 2 \cdot \left[ \frac{R^2}{2} \left( \pi \cdot \frac{\alpha}{180} - \sin \alpha \right) \right] \cdot \left( \frac{A^3}{12 \cdot \left[ \frac{R^2}{2} \left( \pi \cdot \frac{\alpha}{180} - \sin \alpha \right) \right]} - F \right)^2 \end{aligned}$$

$$W_x = \frac{I_x}{E}$$

$$M_B = \frac{1}{2} \cdot \frac{(D^2 \cdot \pi)}{4} \cdot P \cdot \frac{2 \cdot D}{3 \cdot \pi} = \frac{D^3 \cdot P}{12}$$

$$\sigma_{vorth} = \frac{M_B}{W_x}$$

$$\sigma_{zul} = \frac{K}{S}$$

The diagram illustrates a lens system with a lens of thickness  $H$  and focal length  $F$ . The lens is positioned between two points labeled  $X$  and  $1$ . The distance from the lens to the point  $X$  is  $C$ , and the distance from the lens to the point  $1$  is  $S$ . The lens is divided into two halves by a vertical line, with the left half labeled  $A$  and the right half labeled  $K$ . The distance from the lens to the point  $1$  is also labeled  $D$ . The radius of curvature of the lens is  $R$ . The angle between the optical axis and the line connecting the center of curvature to the point  $1$  is  $\alpha$ , and the angle between the optical axis and the line connecting the center of curvature to the point  $X$  is  $\beta$ . The diagram also shows the focal length  $F$  and the distance  $E$  from the lens to the point  $1$ .

1

## DESIGN DATA:-

P(bar)\_\_\_\_\_ Design pressure.  
H( mm)\_\_\_\_\_ Thickness of disc.  
R(mm)\_\_\_\_\_ Radius of curvature.  
y(mm)\_\_\_\_\_ Deflection of disc.  
D(mm)\_\_\_\_\_ Diameter of disc.  
 $\sigma_{zul}$ (MPa)\_\_\_\_\_ Allowable design stress.  
 $\sigma_{vorth}$ (MPa)\_\_\_\_\_ Stress developed in disc.

### 3.2.2 BODY WALL THICKNESS

Following parameters are required for the design of body wall .

- a) Material for wall.
- b) Design factor of safety.

With reference to figure-3.4

$$S_r = \frac{D_a \cdot P1}{20 \cdot \frac{K}{S} \cdot V + P1} + C1 + C2. \quad (3.3)$$
$$\frac{D_a}{D_i} \leq 1.2$$

## DESIGN DATA

Sr (mm)\_\_\_\_\_ Calculated wall thickness.  
Da (mm) \_\_\_\_\_ Body outer diameter.  
Di (mm)\_\_\_\_\_ Body inner diameter.  
P1 (bar)\_\_\_\_\_ Design pressure.  
K (N/sq mm)\_\_\_\_\_ Design stress value.  
S \_\_\_\_\_ Design factor of safety  
V \_\_\_\_\_ Efficiency factor.  
C1( mm ) \_\_\_\_\_ Tolerance allowance.  
C2 (mm ) \_\_\_\_\_ Corrosion allowance.

## BODY WALL THICKNESS

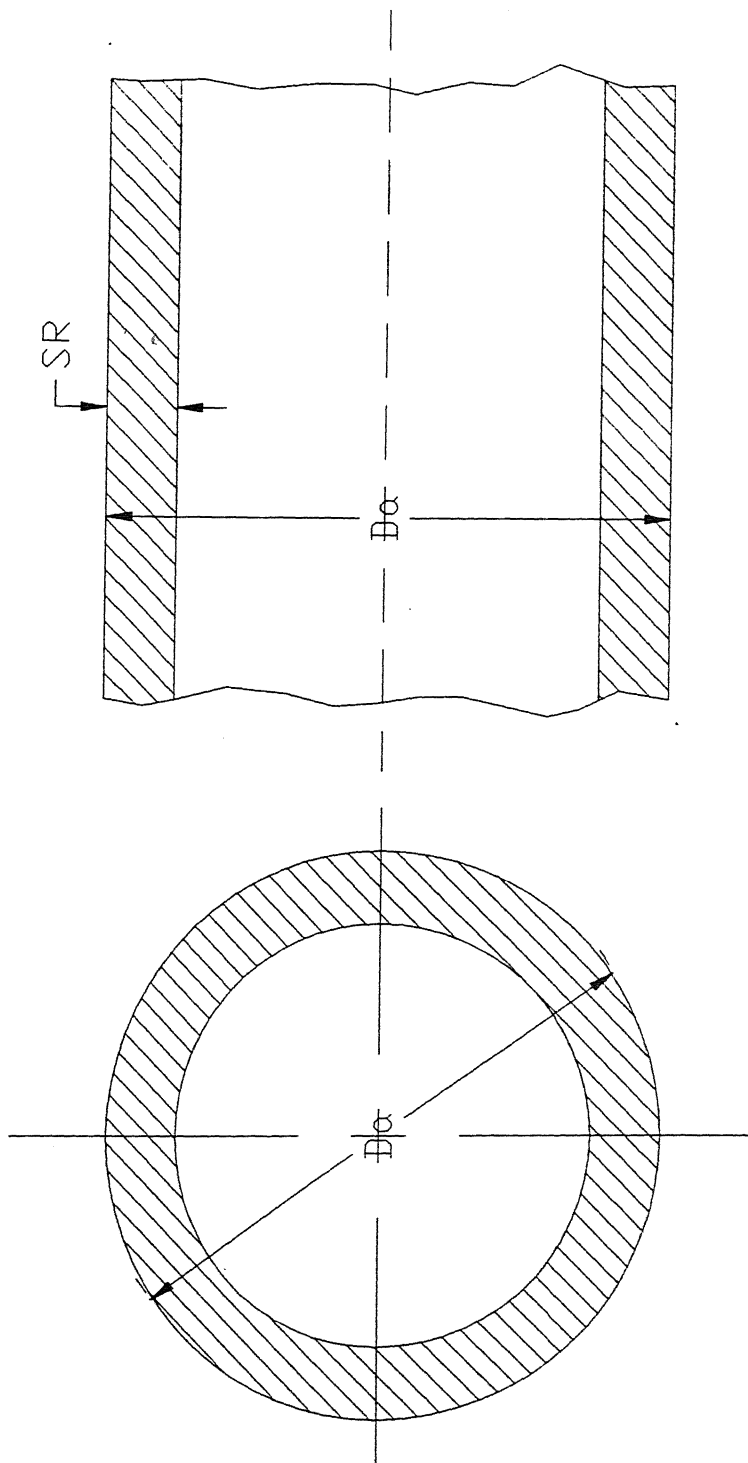


FIGURE 3.4 Sectional view of body wall thickness.

### 3.2.3 CALCULATION OF SHAFT DIAMETER/OFFSET OF SHAFT/SEAT TORQUE/BEARING TORQUE/OFFSET TORQUE/TOTAL TORQUE

The following inputs are required

- a) Material for shaft.
- b) Design factor of safety.
1. The shaft diameter (mm) is obtained from ADAMS Chart attached as appendix C .
2. Seat torques( $T_{seat}$ ) as per valve size is obtained from K138 chart of ADAMS attached as appendix C.
3. Offset of shaft (mm) as per valve size is obtained from K138 chart of ADAMS attached as appendix C.

The torques are calculated as follows:-

$$\text{bearing torque (Tb)} = K_r * 0.785 * D^2 * d/2 * \Delta P * \mu * 100. \quad (3.4)$$

$$\text{Offset torque(Toff)} = 0.785 * D^2 * \text{offset} * \Delta P * 100000.$$

$$\text{Total torque( NM)} = T_b + T_{off} + T_{seat}.$$

#### DESIGN DATA

$K_r$  Bearing torque coefficient

$\mu$  Coefficient of friction

$D$  Valve diameter(M)

$d$  Valve shaft diameter(MM).

$\Delta P$  Working pressure.

Offset (M) Distance between shaft and body center line.

### 3.2.4 STRESS CALCULATION OF VALVE SHAFT DUE TO COMBINED BENDING AND TORSION.

The shaft is subjected to combined bending and torsion affect, and the resultant stress is calculated from the following formulae.

With reference to figure No-3.5

$$M_b = \frac{DN^2 \cdot \pi}{4} * 0.5 \cdot p_2 \cdot a \cdot 10^{-4} \quad (3.5)$$

$$M_v = \sqrt{M_b^2 + 0.75 * (\alpha_0 \cdot Mt)^2}$$

$$\alpha_0 = 0.7 \text{ (Torsion dead \vee growing, bending changing)}$$

$$W = \pi \cdot \frac{d^3}{32}$$

$$\sigma_{vorth} = \frac{M_v}{W} \cdot 10^3$$

$$\sigma_{zul} = \frac{K}{S}$$

#### DESIGN DATA:-

DN (mm) \_\_\_\_\_ Nominal diameter of valve.

P2(bar) \_\_\_\_\_ Design pressure.

a(mm ) \_\_\_\_\_ Moment arm.

Mt(Nm) \_\_\_\_\_ Input torque.

D (mm) \_\_\_\_\_ Shaft outer diameter.

K (N/sq mm) \_\_\_\_\_ Design stress value.

S( ) \_\_\_\_\_ Design factor.

M<sub>b</sub>(N-m) \_\_\_\_\_ Bending moment

σ<sub>zul</sub> (MPa) \_\_\_\_\_ Allowable design stress.

σ<sub>vorth</sub>(MPa) \_\_\_\_\_ Calculated stress in shaft.



# VALVE SHAFT

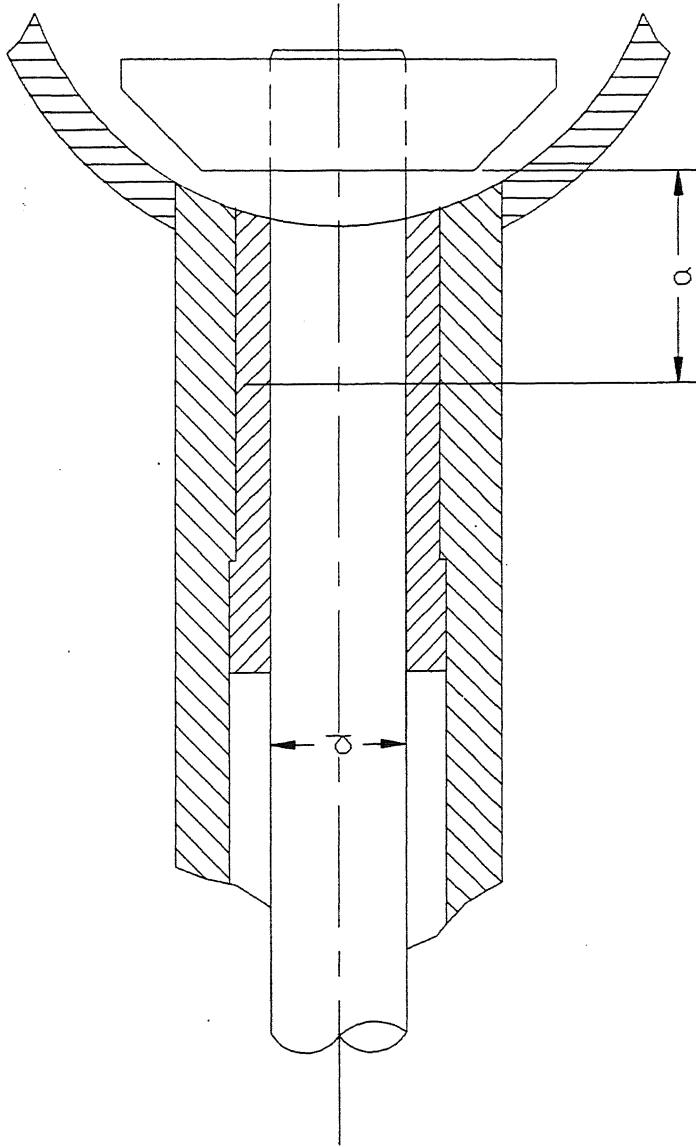


FIGURE 3.5 Sectional view of butterfly valve shaft and bearing.

### 3.2.5 DESIGN OF SHAFT BEARING AND SHAFT SEALS

The shaft bearing in butterfly valve is of Journal type which are designed to withstand the loads due to full differential pressure on the disc when closed. The bearings are generally made of materials to keep the bearing area absolutely clean and free from any dirt particles the line fluid may be carrying. Provision of 'O' ring or packing ring on the location where the shaft enters body is made. This eliminates the possibility of damage to the smooth bearing area and seizure of the shaft bearing.

For shaft sealing arrangement, valves are provided with unique combination of 'U' cup seal and 'O'ring fitted on retaining bush in such a way that no leakage along the shaft will occur. The shaft seal assembly is easily replaceable at site.

The conventional stuffing box packed with flexible material is generally not used to reduce the operating torque requirement of the valve. It also adds to the difficulty in mounting quarter turn operator. The journal bearing is designed as follow:

With reference to figure 3.5

$$F = \pi / 4 * D^2 * p . \quad ( 3.6 )$$

$$\text{Bearing length} = 0.5 * F / \text{bearing stress} * d .$$

$$\text{Clearance (mm )} = 0.02 * d .$$

$$\text{Thickness of bush (mm)} = 0.08 * d + 0.3 .$$

$$\text{Collar diameter} = 1.2 * d .$$

#### DESIGN DATA.

D (mm ) \_\_\_\_\_ Diameter of valve.

P (bar) \_\_\_\_\_ Design pressure.

d( mm ) \_\_\_\_\_ Diameter of shaft.

### 3.2.6 DESIGN / STRESS ANALYSIS FOR SHAFT KEYS

Butterfly valve uses SUNK KEY OF RECTANGULAR CROSS SECTION for shaft torque transmission. This requires the following inputs for design of key :

- a) Material for key design.
- b) Design factor of safety.
- c) Numbers of keys .

With reference to figure No-3.6

$$U = d + 13.0 \quad (3.7)$$

$$b = \frac{U}{4}$$

$$L = 1.5 * U.$$

$$h = \frac{U}{6}$$

$$\text{height } h1 = 0.5(\sqrt{d^2 - b^2} - d + 2.t1)$$

$$\text{height } h2 = h - h1.$$

surface stress  $\in$  shaft

$$\sigma 1 = \frac{2M_T}{(d - h1).(c - b).h1.n}$$

surface stresses  $\in$  Hub

$$\sigma 2 = \frac{2.M_T}{(d + h2).(c - b).h2.n}$$

#### DESIGN DATA:-

Mt (Nm)\_\_\_\_\_ Torque.

d(mm)\_\_\_\_\_ Shaft outer diameter.

t1(mm)\_\_\_\_\_ Depth Of shaft key.

H (mm)\_\_\_\_\_ Height of key.

L(mm)\_\_\_\_\_ Length of key.

b(mm)\_\_\_\_\_ Width Of key.

n( ) \_\_\_\_\_ Number of keys.

# KEY WITH SHAFT

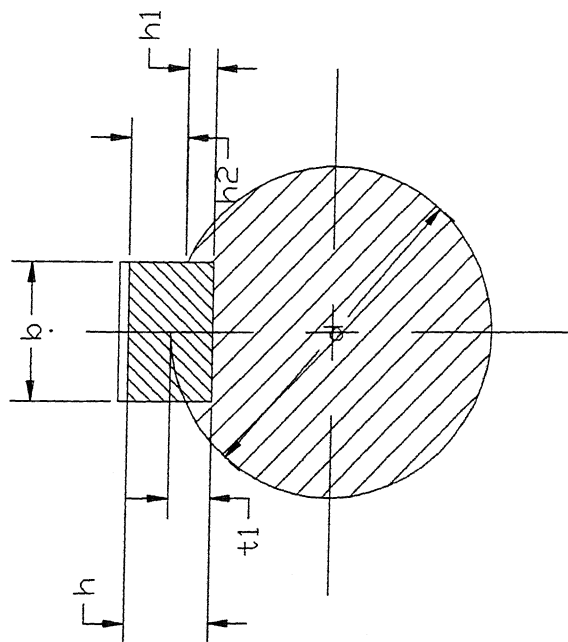


FIGURE 3.6 Sectional view of shaft with key.

# SPLIT THRUST RING

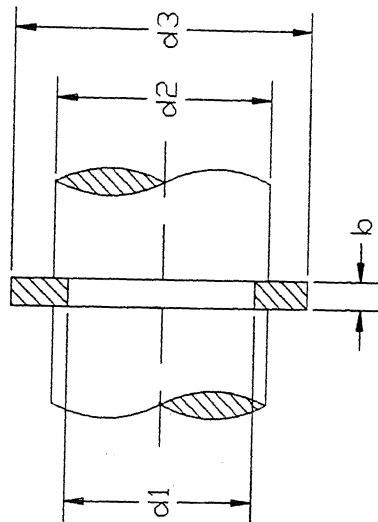


FIGURE 3.7 Sectional view of split thrust ring.

### 3.2.7 DESIGN AND STRESS ANALYSIS OF SPLIT THRUST RING

Split thrust ring is provided at the non driving end (NDE) of shaft to prevent its axial movements. This requires the following inputs for design of split thrust ring :

- Material for split thrust ring design.
- Design factor of safety.

With reference to figure No- 3.7

$$\begin{aligned} d1 &= 0.9 * d2. \\ d3 &= 1.2 * d2. \end{aligned} \quad (3.8)$$

$$\text{Bearing stress} = \frac{4 \cdot \pi \cdot d2^2 \cdot p}{4 \cdot \pi \cdot (d2^2 - d1^2)}$$

$$\text{Bending stress} = \frac{d2^2 \cdot (d2 - d1) \cdot p}{4 \cdot b^2 \cdot (d3 - d1)}$$

#### DESIGN DATA:-

- d1 (mm) \_\_\_\_\_ Inner diameter of split thrust ring.  
d2 (mm) \_\_\_\_\_ Shaft diameter.  
d3(mm) \_\_\_\_\_ Outer diameter of split thrust ring.  
p ( Bar) \_\_\_\_\_ Design Pressure.  
b (mm) \_\_\_\_\_ Width of split ring.

### 3.2.8 DESIGN OF LOCKING CAP / BOLTS FOR LOCKING CAP

The purpose of locking cap arrangement is to keep valve disc locked either in fully closed position or in fully open position in the event of necessity to remove gear box for maintenance while keeping the valve in the pipe line. Locking cap is fitted on valve body for non driving end (NDE) shaft. The locking cap has a suitable bore to receive NDE shaft. Two keys are provided for engaging locking cap with NDE shaft which are normally not engaged during operation of the valve. The disc can be locked in close and open position simply by inserting keys between locking cap and NDE

shaft. Grub screws are also provided to screw the keys in position.

The locking cap is designed to carry full torque. The torque from the shaft goes to the locking cap through keys. This torque is supplied in the form of frictional grip between the locking cap flange and valve flange. The connecting bolts is suitably designed.

The following inputs are required for design:

- a) Material for cap and bolts.
- b) Design factor of safety for cap and bolts .
- c) Total numbers of bolts required.

Torque is transmitted in two ways.

$$r1 = 1.5 * r. \quad (3.9a)$$

$$r2 = 3.0 * r.$$

$$p.c.d = 2.0 * \left( \frac{r1 + r2}{2} \right)$$

$$shear\ force(F1) = \frac{T * 1000.0}{r1}.$$

$$Thickness(t) = \frac{F}{2.\pi.r1.Design\ stress}$$

\*) Frictional torque between two flanges.

\*\*) Shear in bolts.

As a safer assumption it could be assumed that all the torque is transmitted as explained in condition \*)

$$Frictional\ torque(T) = \frac{2}{3} . \pi . (r2^3 - r1^3) . p. \quad (3.9b)$$

$$Area(A) = \pi . (r2^2 - r1^2)$$

$$Load(F2) = p . A . N.$$

$$Bolt\ area(A_c) = \frac{F}{N * Design\ stress}$$

$$Core\ diameter(d_o) = \frac{\sqrt{4.0 * A_c}}{\pi}$$

## DESIGN DATA

$r_1$  (mm) \_\_\_\_\_ Inner radius of locking cap.  
 $r_2$  (mm) \_\_\_\_\_ Outer radius of locking cap.  
 $T$  (N-m) \_\_\_\_\_ Total torque.  
 $F_1$  (N) \_\_\_\_\_ Shear force.  
 $F_2$  (N) \_\_\_\_\_ Total load.  
 $t$  (mm) \_\_\_\_\_ Thickness of cap.  
 $N$  ( ) \_\_\_\_\_ Number of bolts.  
 $A_c$  (sq-mm) \_\_\_\_\_ Core area of bolt.  
 $d_c$  (mm) \_\_\_\_\_ Core diameter of bolt.

### 3.2.9 STRESS ANALYSIS FOR VALVE FLANGE

Flanges of standard dimensions as per Indian Standards I.S:6392-1971[11] are available in the market. Hence stress analysis of flange of standard dimensions is only required. The following data are needed for stress analysis:-

- Material for flange.
- Design factor of safety.
- Standard dimensions of valve flange as per I.S.code IS:6392-1971

The stress analysis is done as follows:-

Reference is made to figure 3.8

continued on next page:-

$$P_{RP} = p l \cdot \frac{\pi}{4} \cdot d^2 \cdot 10^{-1} \quad (3.10)$$

$$P_R = P_{RP} + P_{RZ}$$

$$P_F = p l \frac{\pi}{4} \cdot (d_D^2 - d^2) \cdot 10^{-1}$$

$$P_{DB} = p l \cdot \pi \cdot d_D \cdot k l \cdot s_D \cdot 10^{-1}$$

$$a_R = 0.5 \cdot (d_t - d - S_R)$$

$$a_F = 0.25 \cdot (2 \cdot d_t - d - d_D)$$

$$a_D = 0.5 \cdot (d_t - d_D)$$

$$M_1 = P_R \cdot a_R + P_F \cdot a_F + P_{DB} \cdot a_D$$

$$a_1 = 0.5 \cdot (d_t - d) - s_F$$

$$P_S = P_{SB} = P_R + P_F + P_{DB}$$

$$M_2 = P_S \cdot a_1$$

$$d'_L = d_L \left( 1 - \frac{d}{1000} \right) \quad \text{for } d < 500 \text{ mm}$$

$$d'_L = 0.5 \cdot d_L \quad \text{for } d \geq 500 \text{ mm}$$

$$S_L = \frac{P_R}{\pi \cdot (d + S_R) \cdot K}$$

$$W_{A-A} = \frac{\pi}{4} \cdot \left[ (d_a - d - 2 \cdot d'_L) \cdot h_F^2 + (d + s_F) \cdot (s_F^2 - s_L^2) \right]$$

$$e = \frac{(d_a - d - 2 \cdot d'_L) \cdot \frac{h_F^2}{2} + (h_a - h_F) \cdot (S_F + S_R) \cdot \left( h_F + \frac{h_a - h_F}{3} \cdot \frac{2 \cdot S_R + S_F}{S_R + S_F} \right)}{(d_a - d - 2 \cdot d'_L) \cdot h_F + (h_a - h_F) \cdot (S_F + S_R)}$$

$$W_{B-B} = \pi \cdot \left[ (d_a - d - 2 \cdot d'_L) \cdot e^2 + \frac{1}{4} (d + S_R) (S_R^2 - S_L^2) \right]$$

$$W_{C-C} = \frac{\pi}{4} \cdot h_F^2 (d_a - 2 \cdot d'_L)$$

$$\sigma_1 = \frac{M_1}{W_{A-A}}$$

$$\sigma_2 = \frac{M_1}{W_{B-B}}$$

$$\sigma_3 = \frac{M_2}{W_{C-C}}$$

$$\sigma_{zul} = \frac{K}{S \cdot Z}$$



# VALVE FLANGE

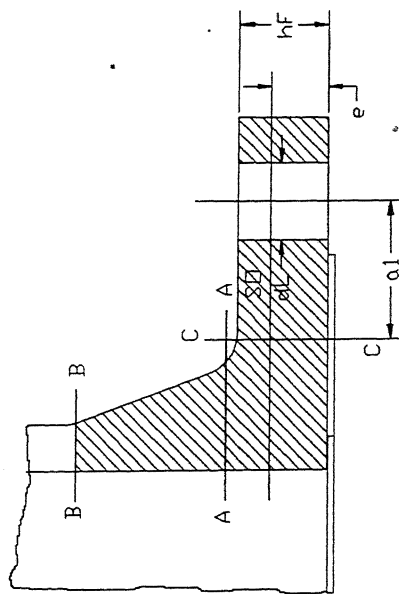
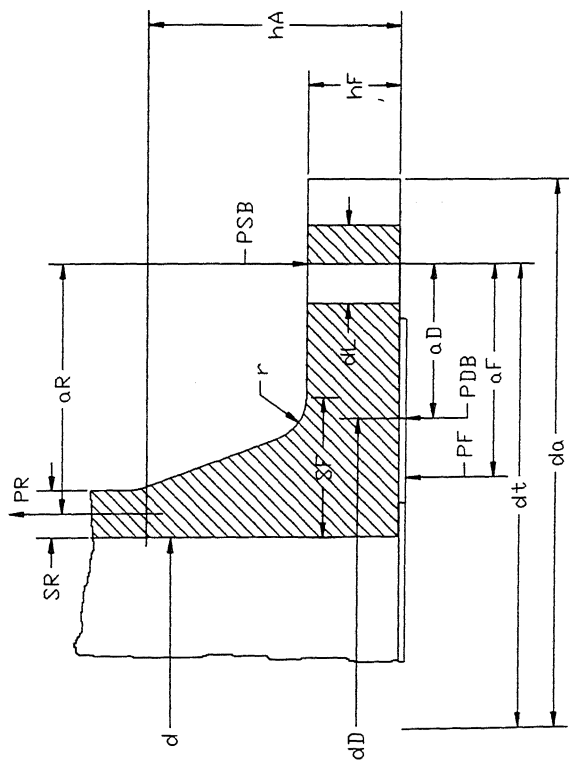


FIGURE 3.8 Sectional view of valve flange.

## DESIGN DATA

$d(\text{mm})$  \_\_\_\_\_ Body/flange inner diameter.  
 $d_a(\text{mm})$  \_\_\_\_\_ Flange outer diameter.  
 $d_t(\text{mm})$  \_\_\_\_\_ Bolt circle diameter.  
 $d_L(\text{mm})$  \_\_\_\_\_ Diameter of bolt holes.  
 $h_F(\text{mm})$  \_\_\_\_\_ Flange thickness.  
 $h_A(\text{mm})$  \_\_\_\_\_ Length of flange through hub.  
 $S_F(\text{mm})$  \_\_\_\_\_ Thickness of hub at the back of flange.  
 $S_R(\text{mm})$  \_\_\_\_\_ Thickness of hub at small end.  
 $K(\text{N/sq mm})$  \_\_\_\_\_ Design stress value.  
 $p_1(\text{Bar})$  \_\_\_\_\_ Design pressure.  
 $d_D(\text{mm})$  \_\_\_\_\_ Diameter at the location of gasket load reaction.  
 $S( \_ )$  \_\_\_\_\_ Design factor of safety.  
 $Z( \_ )$  \_\_\_\_\_ Factor for correction of allowable stress considering deformation properties of material.  
 $P_{RZ}( - )$  \_\_\_\_\_ Additional pipe forces for unspecified conditions.  
 $\sigma_{zul}(\text{MPa})$  \_\_\_\_\_ Allowable design stress.  
 $\sigma_1(\text{MPa})$  \_\_\_\_\_ Calculated stress in flange through section A-A.  
 $\sigma_2(\text{MPa})$  \_\_\_\_\_ Calculated stress in flange through section B-B.  
 $\sigma_3(\text{MPa})$  \_\_\_\_\_ Calculated stress in flange through section C-C.

### 3.2.10 STRESS CALCULATION FOR SHAFT FLANGE

These are available in standard dimensions as per I.S code IS:6392-1971[ ]. The following input data are required for stress analysis:-

- Material for flange.
- Design factor of safety.
- Dimensions as per I.S.Standards

The stress analysis is done as follows:

With reference to figure 3.9

$$P_R = p l \cdot \frac{\pi}{4} \cdot (d_i^2 - d_w^2) \cdot 10^{-1} \quad (3.11)$$

$$a_R = \frac{1}{2} [d_t - (d_i + S_R)]$$

$$M_1 = P_R \cdot a_R$$

$$d'_L = d_L \cdot \left(1 - \frac{d_i}{1000}\right) \quad \text{for } d < 500 \text{ mm}$$

$$S_L = \frac{P_R}{\pi (d_i + S_R) \cdot K}$$

$$W_{A-A} = 0.9 \cdot \frac{\pi}{4} [(d_a - d_2 - 2d'_L) h_F^2 + (d_i + S_R) \cdot (S_R^2 - S_L^2)]$$

$$\sigma_{\text{vorth}} = \frac{M_1}{W_{A-A}}$$

$$\sigma_{zul} = \frac{K}{S \cdot Z}$$

$$W_p = 2 \cdot \frac{\pi}{32} \cdot \frac{d_2^4 - d_i^4}{d_a}$$

$$\tau_{\text{tvorth}} = \frac{M_t}{W_p}$$

$$\tau_{zul} = \frac{\sigma \cdot 0.2}{2.3}$$

$$\alpha o = \frac{\sigma_{zul}}{1.73 \cdot \tau_{zul}}$$

$$\sigma_{Vzul} = \sqrt{\sigma_{zul}^2 + 3 \cdot (\alpha o \cdot \tau_{zul})^2}$$

$$\sigma_v = \sqrt{\left(\frac{M_1}{W_{A-A}}\right)^2 + 0.75 \left(\alpha o \cdot \frac{M_t}{W_p}\right)^2}$$

# SHAFT FLANGE

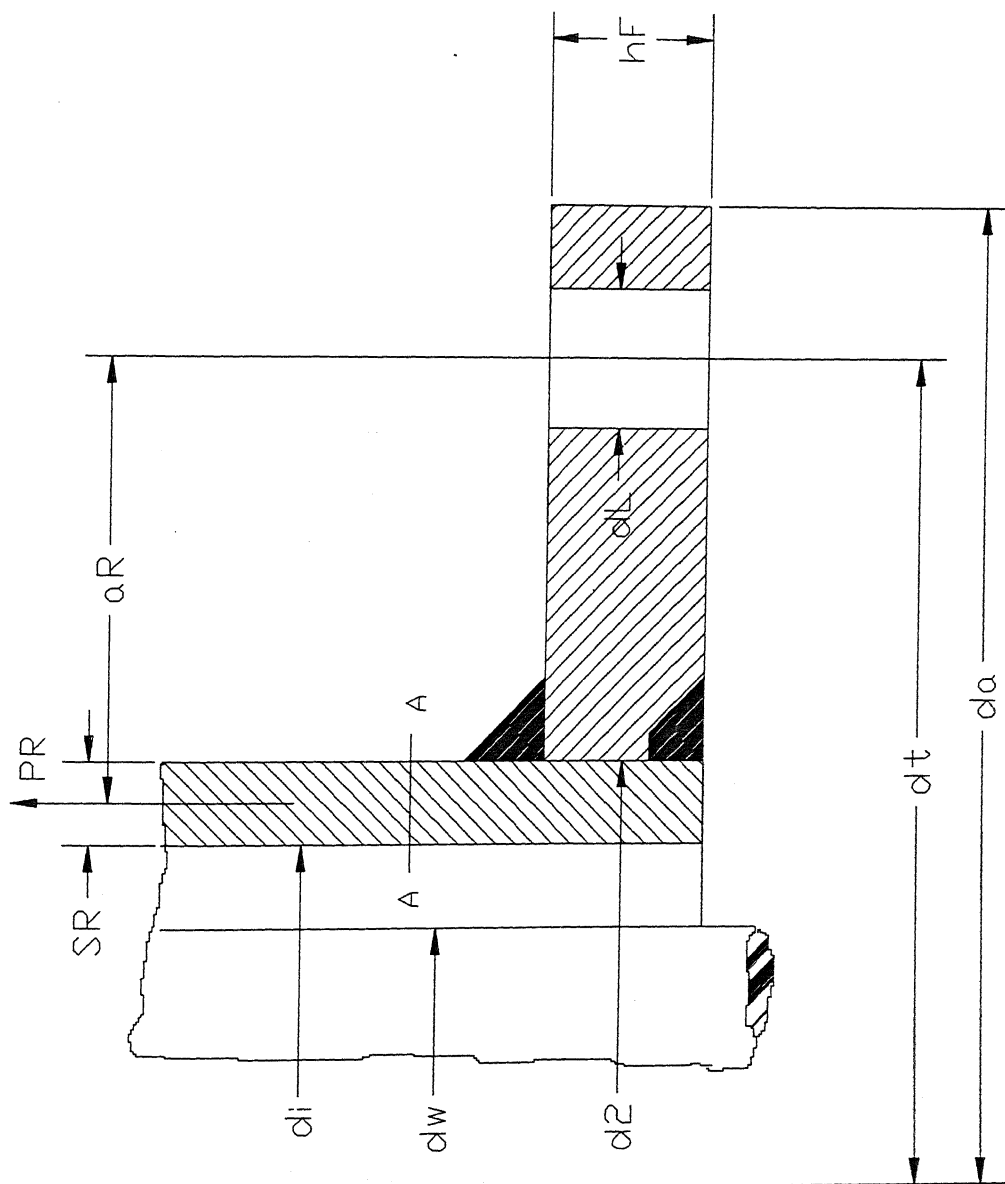


FIGURE 3.9 Sectional view of shaft flange.

#### DESIGN DATA:-

$d_i$  (mm ) \_\_\_\_\_ Flange inner diameter.

$d_w$ (mm)\_\_\_\_\_ Shaft Diameter.

$d_t$ (mm)\_\_\_\_\_ Bolt circle diameter.

$d_a$ (mm)\_\_\_\_\_ Flange outer diameter.

$d_2$ (mm)\_\_\_\_\_ Pipe outer diameter.

$d_L$ (mm)\_\_\_\_\_ Dowel circle diameter.

$h_F$ (mm)\_\_\_\_\_ Flange thickness.

$SR$ (mm)\_\_\_\_\_ Bearing house wall thickness.

$K$ (MPa)\_\_\_\_\_ Design stress value.

$p_l$ (Bar)\_\_\_\_\_ Design pressure.

$S$ ( \_ )\_\_\_\_\_ Design factor of safety.

$\sigma_{vzul}$ (MPa)\_\_\_\_\_ Allowable design stress.

$\sigma_v$ (MPa)\_\_\_\_\_ Calculated stress in body wall through section A-A.

#### 3.2.11 DESIGN OF COVER FOR BODY NON DRIVING END

Select following inputs for design of cover:-

a) Material for cover.

b) Design factor of safety.

Reference is made to figure 3.10

$$d_{si} = 1.2 * \text{Shaft dia.} \quad (3.12)$$

$$d_{so} = 1.2 * \text{Shaft dia} + 2.0 * \text{Wall thickness.}$$

$$d_D = \frac{(d_{si} + d_{so})}{2}.$$

$$s = 1.2 * d_D * \sqrt{p_l \cdot \frac{S}{10.K}}$$

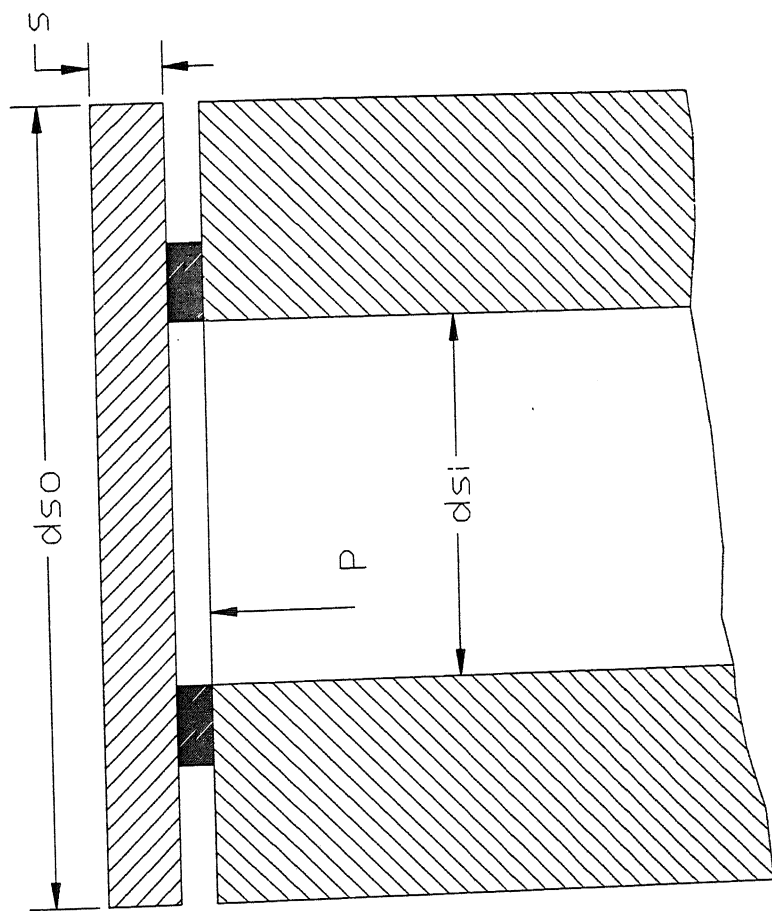


FIGURE 3.10 Sectional view of cover at non driving end.

### DESIGN DATA:-

$d_D$  \_\_\_\_\_ Diameter at location of gasket.

$p_i$  \_\_\_\_\_ Design pressure.

$s( \_ )$  \_\_\_\_\_ Design factor of safety.

$K(N/sq. mm)$  \_\_\_\_\_ Design stress value.

### 3.3 SUMMARY

In this chapter, sizing of butterfly valve using nomograph technique was discussed. The design methodology of parts and their stress analysis is also discussed, and equations used are mentioned.

# **CHAPTER -4**

## **DESIGN ALGORITHM AND TRIAL RUNS**

### **4.1 INTRODUCTION**

In this chapter, a stepwise procedure for the sizing of butterfly valves and design of its parts are given. The connectivity of the various segments and package implementation is attached as Appendix B, and a detail trial run of the package is at the end of this chapter. In this package, extensive use of MATLAB has been used for curve fitting of charts and expressing them as a polynomial functions, suitable for computer applications. Thus, this program stores most of the charts like NOMOGRAPH, ADAMS CHART, MOODY CHART ( used to find friction factor for pipes) in a retrievable form which is other wise difficult to be read by a computer. The material data structure has also been made which helps in selection of materials for parts, the data structure can easily be changed by users in the program depending upon their requirements. These are discussed as and when they are encountered in the program.

### **4.2 MATERIAL DATA BASE**

For designing a butterfly valve, each component of it is to be made of different type of material depending upon its requirement and usage. In the program, list of material along with its code is displayed on the screen . These material database is selected from various sources like I.S.I, B.S, AISI and some feed back from leading manufacturers[ 8] in this field. Display of the list of material along with its code for each part design, helps the designer for easy selection of materials and cut down the design time, instead of referring to various codes and books for it. The list of material along with its code is shown below. The code number facilitates the selection of the material by the users.



#### 4.2.1 BUTTERFLY VALVE DISC

| MATERIAL        | I.S GRADE     | CODE |
|-----------------|---------------|------|
| GREY IRON       | FG 15         | 1    |
|                 | FG 20         | 2    |
|                 | FG 35         | 3    |
| SPHEROIDAL      | SG 80/2       | 4    |
| GRAPHITE IRON   | SG 60/2       | 5    |
|                 | SG 38/2       | 6    |
| ALLOY CAST IRON | Ni-Mo.CI      | 7    |
|                 | NITRALLOY C.I | 8    |

#### 4.2.2 BODY WALL THICKNESS

| MATERIAL           | I.S GRADE      | CODE |
|--------------------|----------------|------|
| GREY IRON          | FG 15          | 1    |
|                    | FG 20          | 2    |
|                    | FG 25          | 3    |
|                    | FG 30          | 4    |
|                    | FG 35          | 5    |
|                    | FG 40          | 6    |
|                    | SG 80/2        | 7    |
|                    | SG 60/2        | 8    |
| ALLOY CAST<br>IRON | Nickel C.I     | 9    |
|                    | Ni-Mo C.I      | 10   |
|                    | Nitraalloy C.I | 11   |
| STEEL              | C 10           | 12   |

#### 4.2.3 SHAFT DIAMETER

| MATERIAL SPECIFICATION        | CODE |
|-------------------------------|------|
| <hr/>                         |      |
| ST.ST.BS970,431/S39/ST.ST.410 | 1    |
| AISI 316/AISI 304             | 2    |

#### 4.2.4 COLLARED BRONZE BEARING

| MATERIAL SPECIFICATION         | CODE |
|--------------------------------|------|
| <hr/>                          |      |
| CHILLED BRONZE BUSHING         | 1    |
| STEEL BUSHING WITH LIGHT LINER | 2    |

#### 4.2.5 KEY

| MATERIAL SPECIFICATION | CODE |
|------------------------|------|
| <hr/>                  |      |
| ST.ST.970Gr316(B.S)    | 1    |
| I.S C-45               | 2    |
| I.S C-50               | 3    |
| I.S C-55               | 4    |
| I.S C-65               | 5    |

#### 4.2.6 SPLIT THRUST RING

| MATERIAL SPECIFICATION | CODE |
|------------------------|------|
| <hr/>                  |      |
| AISI 410               | 1    |
| I.S C-40               | 2    |
| I.S C-50               | 3    |
| I.S C-55 Mn75          | 4    |

## 4.2.7 DESIGN OF LOCKING CAP

| MATERIAL SPECIFICATION | CODE |
|------------------------|------|
|------------------------|------|

|          |   |
|----------|---|
| S.G 80/2 | 1 |
| S.G 60/2 | 2 |

## 4.2.8 BOLTS FOR LOCKING CAP

| MATERIAL SPECIFICATION | CODE |
|------------------------|------|
|------------------------|------|

|       |   |
|-------|---|
| C20   | 1 |
| C45   | 2 |
| C60   | 3 |
| St.55 | 4 |
| 40CrI | 5 |

## 4.2.9 VALVE FLANGE .

| MATERIAL SPECIFICATION | CODE |
|------------------------|------|
|------------------------|------|

|           |   |
|-----------|---|
| F.G.40    | 1 |
| S.G42/2   | 2 |
| S.G60/2   | 3 |
| S.G 80/2  | 4 |
| 35Mn2Mo28 | 5 |

#### 4.2.10 COVER FOR BODY NDE

| MATERIAL SPECIFICATION | CODE |
|------------------------|------|
|------------------------|------|

|     |   |
|-----|---|
| C10 | 1 |
| C20 | 2 |
| C30 | 3 |
| C45 | 4 |
| C50 | 5 |

#### 4.2.11 SHAFT FLANGE STRESS

| MATERIAL SPECIFICATION | CODE |
|------------------------|------|
|------------------------|------|

|       |   |
|-------|---|
| C20   | 1 |
| C45   | 2 |
| C60   | 3 |
| St.55 | 4 |
| 40CrI | 5 |

### 4.3 CURVE FITTING FOR NOMOGRAPH

The nomographs (figure 3.1,3.2 ) which are used for sizing of butterfly valves give relationship between percentage flow rate and disc angle for various value of K-factors in the form of curves. These curves are converted into polynomial functions by curve fitting techniques, a facility available in MATLAB package.

To improve the accuracy for curve fitting, the complicated curves were broken into segments and then curve fitting was done separately for each curve. The polynomial functions used in the program were upto 20 decimal places to improve accuracy, however here it is shown

upto two decimal places only.

#### 4.3.1 NOMOGRAPH (FIGURE 3.1) AS A POLYNOMIAL FUNCTION

This nomograph which represents relationship between percentage flow rate and disc angle for different values of head loss factor (K), is first converted into four polynomial function  $\theta_1, \theta_4, \theta_{16}, \theta_{64}$  for  $K=1, 4, 16, 64$ . respectively.

The nomograph is expressed as polynomial function as follows.

$$\theta_1 = 1.58e-4 Q^3 - 2.84e-2 Q^2 + 2.06 Q + 6.604 \quad (4.1)$$

$$\theta_4 = 1.18e-4 Q^3 - 1.88e-2 Q^2 + 1.46 Q + 4.122.$$

$$\theta_{16} = 1.90e-4 Q^3 - 2.53e-2 Q^2 + 1.36 Q + 7.58e-1.$$

$$\theta_{64} = 2.08e-4 Q^3 - 2.67e-2 Q^2 + 1.21 Q + 5.5e-1.$$

where Q is the percentage flow rate.

The disc angle ( $\alpha$ ) is determined using above equations and interpolation is done for in between positions as follow.

For  $K = 1$ .

$\alpha = \theta_1$ .

For  $K = 4$ .

$\alpha = \theta_4$ .

For  $K = 16$ .

$\alpha = \theta_{16}$ .

for  $K = 64$ .

$\alpha = \theta_{64}$ .

For  $(1 < K < 4)$

$$\alpha = \theta_1 + (\theta_1 - \theta_4) * (1 - K) / 3 .$$

For  $(4 < K < 16)$

$$\alpha = \theta_4 + (\theta_4 - \theta_{16}) * (4 - K) / 12.$$

For  $(16 < K < 64)$

$$\alpha = \theta_{16} + (\theta_{16} - \theta_{64}) * (16 - K) / 48.$$

The optimal angle is calculated for 10% and 90% of flow rate using above equations.

#### 4.3.2 NOMOGRAPH (FIGURE 3.2) AS POLYNOMIAL FUNCTION

This Nomograph gives the relationship between butterfly valve loss coefficient ( $K_v$ ) and disc opening angle, which is represented in the form of curve. MATLAB has been used to find polynomial functions using curve fitting techniques. The range of  $K_v$  is very large (i.e 0.5 to 80,000), it would have been difficult to fit a single curve which may lead to very high powers and still not be accurate, hence the curve has been broken into segments to improve accuracy. The Nomograph curve shown in figure 3.2 is expressed as polynomial functions below.

$$\text{For } (20,000 \leq K < 80,000) \quad (4.2)$$

$$\text{angle} = 2.77\text{e-}18 K^4 - 5.27\text{e-}13 K^3 + 3.44\text{e-}8 K^2 - 9.49\text{e-}4 K + 1.81\text{e}1.$$

$$\text{For } (2000 \leq K < 20,000)$$

$$\text{angle} = -1.9\text{e-}12 K^3 + 7.82\text{e-}8 K^2 - 1.16\text{e-}3 K + 1.72\text{e}01.$$

$$\text{For } (400 \leq K < 2000)$$

$$\text{angle} = -3.31\text{e-}9 K^3 + 1.382\text{e-}5 K^2 - 1.98\text{e-}2 K + 2.48\text{e}01.$$

$$\text{For } (30 \leq K < 400)$$

$$\text{angle} = -2.219\text{e-}6 K^3 + 1.45\text{e-}3 K^2 - 2.83\text{e-}1 K + 4.2\text{e}1.$$

$$\text{For } (0.5 \leq K < 3.0)$$

$$\text{angle} = 1.12\text{e}1 K^3 + 6.5\text{e}1 K^2 - 1.18\text{e}2 K + 1.34\text{e}2.$$

#### 4.4 CALCULATION OF K-FACTOR FOR PIPES

The head loss in the pipe lines is given by

$$H_L = K V^2 / 2g \quad (4.3)$$

$$\text{Where } K = f L / D$$

Where  $f$  is the friction factor for pipe,  $D$  is the pipe diameter, and  $L$  is the length.

For this determination of friction factor ( $f$ ) is necessary, which is expressed in the form of Moody's chart (figure 4.1). This chart has been expressed in the form of equation for computer to store Moody chart in retrievable form which is discussed below.

Select material of pipe as displayed on screen, which makes program to select absolute roughness ( $e$ ) in meters.

MATERIALS FOR PIPE

ABSOLUTE ROUGHNESS ( $e$ ) IN METERS

a) Glass, new commercial pipe surface

1.52 e-6

drawn tubing(brass,copper,lead)

|                                     |                    |
|-------------------------------------|--------------------|
| b) Commercial steel or wrought iron | 4.57e-5            |
| c) Asphalted cast iron              | 1.22e-4            |
| d) Galvanized                       | 1.52e-4            |
| e) cast iron                        | 2.59e-4            |
| f) Wood stove                       | 2.59e-4            |
| g) Concrete                         | 1.83e-4 to 9.14e-5 |
| h) Riveted steel                    | 3.05e-4 to 3.05e-3 |

Calculate Reynold number (Re)

$$Re = \rho v d / \mu.$$

Where  $\mu$  is the kinematic viscosity and  $\rho$  is the density of the fluid.

Calculate friction factor (f )

For  $Re > 10^4$  i.e turbulent and  $10^{-5} < G < 0.04$

were  $G = e / d$

$$f = a + b Re^{-c} \quad (4.4)$$

$$a = 0.094 G^{0.225} + 0.53 G.$$

$$b = 88 G^{0.44}$$

$$c = 1.62 G^{0.134}$$

Once friction factor( f ) is known, K factor is determine from equation (4.3)

#### 4.5 ADAM'S CHART AS POLYNOMIAL FUNCTIONS

The ADAM'S chart attached as Appendix C, are first converted into graph and then their polynomial functions by curve fitting technique of MATLAB.

The ADAM's CHART is used to find.

- Shaft diameter as per valve size.
- Seat torque as per valve size.
- Valve offset as per valve size.

##### 4.5.1 SHAFT DIAMETER (d)

Reference is made to figure 4.1, 4.2. This figure gives relationship between shaft diameter and

valve size as per material selected.

-For material : St.St.B.S 970,431 s/29 St.St.410 heat treated.

For (  $P > 0.0$  and  $P \leq 6.0$  )

$$d = 1.072e-8 D^3 - 4.5e-5 D^2 + 0.13D - 0.6856.$$

For (  $P > 6.0$  and  $P \leq 16$  )

$$d = 3.59e-9 D^2 + 0.08 D + 25.58$$

For (  $P > 10$  and  $P \leq 16$  )

$$d = -0.0001D^2 + 0.3667 D - 170.0.$$

were  $P$  is the pressure in Bar and  $D$  is the disc diameter in mm.

-For material : AISI 316 / AISI 304

For (  $P > 0.0$  and  $P \leq 6.0$  )

$$d = 1.99e-8 D^3 - 6.86e-5 D^2 + 1.66e-1D + 4.71e-1.$$

For (  $P > 6.0$  and  $P \leq 10.0$  )

$$d = 1.36e-5D^2 + 1.64e-1D - 4.95e-1.$$

For (  $P > 10.0$  and  $P \leq 16$  )

$$d = 1.77e-5 D^2 + 1.45e-1 D - 3.27e-2.$$

#### 4.5.2 SEAT TORQUE

Reference is made to figure 4.4. This gives the relation ship between seat torque and valve size.

$$\text{Seat torque} = 2.207e-6D^3 - 8.57e-4D^2 + 2.65D - 2.37e2.$$

#### 4.5.3 VALVE OFFSET

$$\text{Offset} = 1.72e-9 D^3 - 7.356e-6 D^2 + 0.102D + 0.1825.$$

In all the above cases, in finding the polynomial functions by curve fitting techniques by MATLAB, an error was observed in the range of 2 to 8.5 percent, even after taking accuracy of twenty decimal places, and breaking the curve into small segments. This error is negligible as far as this package is concerned, because valves are made in discrete size (10, 15, 25 ..... ) due to availability of off the shaft flanges in standard sizes in the market, thus the calculated valve size is always rounded off to next higher size to meet the flange size available in the market. The shaft diameter calculated by ADAMS CHART always under go stress analysis, where proper factor of safety is built in. Hence any small error in this case can also be ignored.



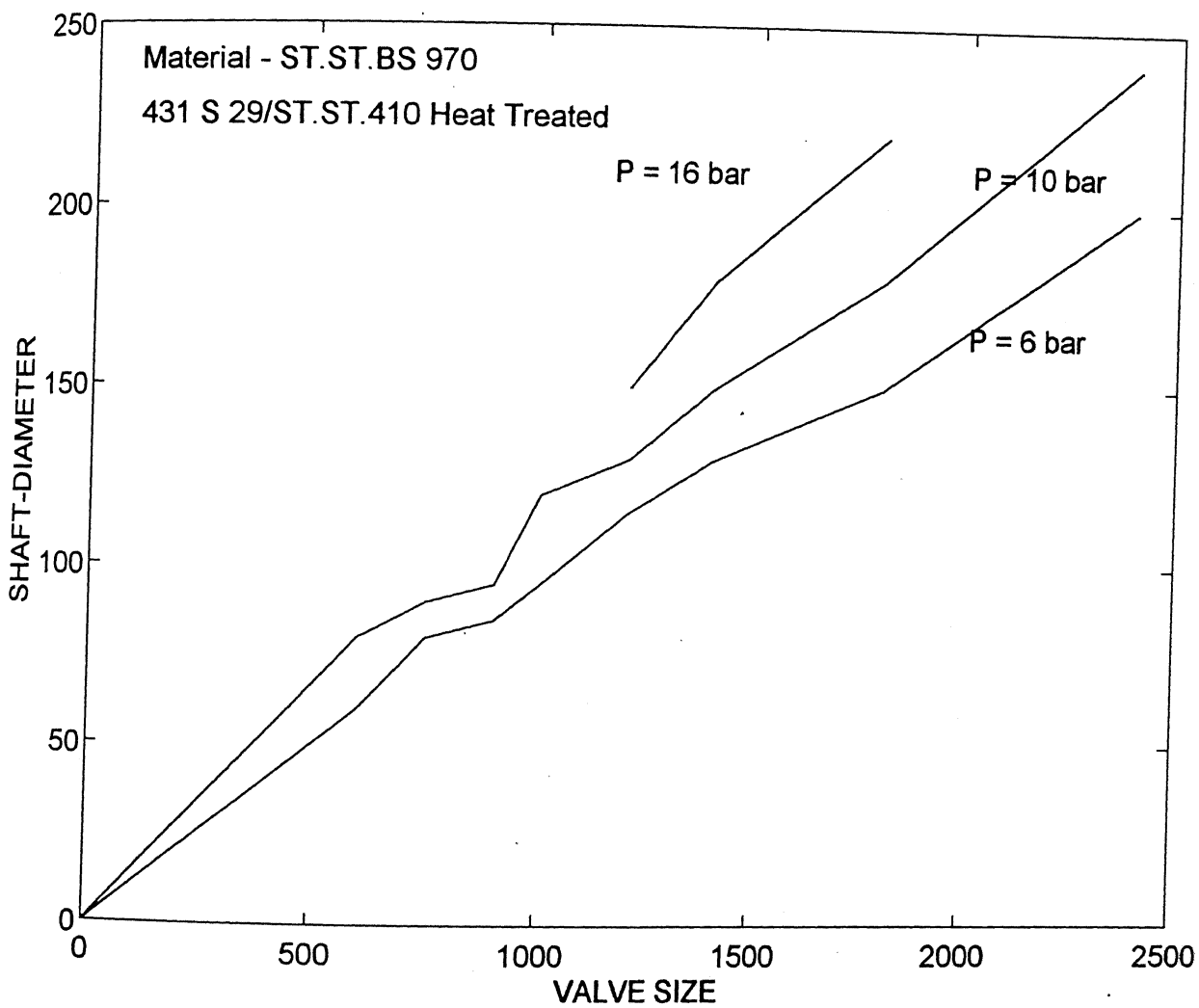


FIGURE 4.1 Relation ship of shaft diameter to valve disc at different pressure.  
( MATERIAL - ST.ST.BS 970,431S 29/ST.ST.410 HEAT TREATED)

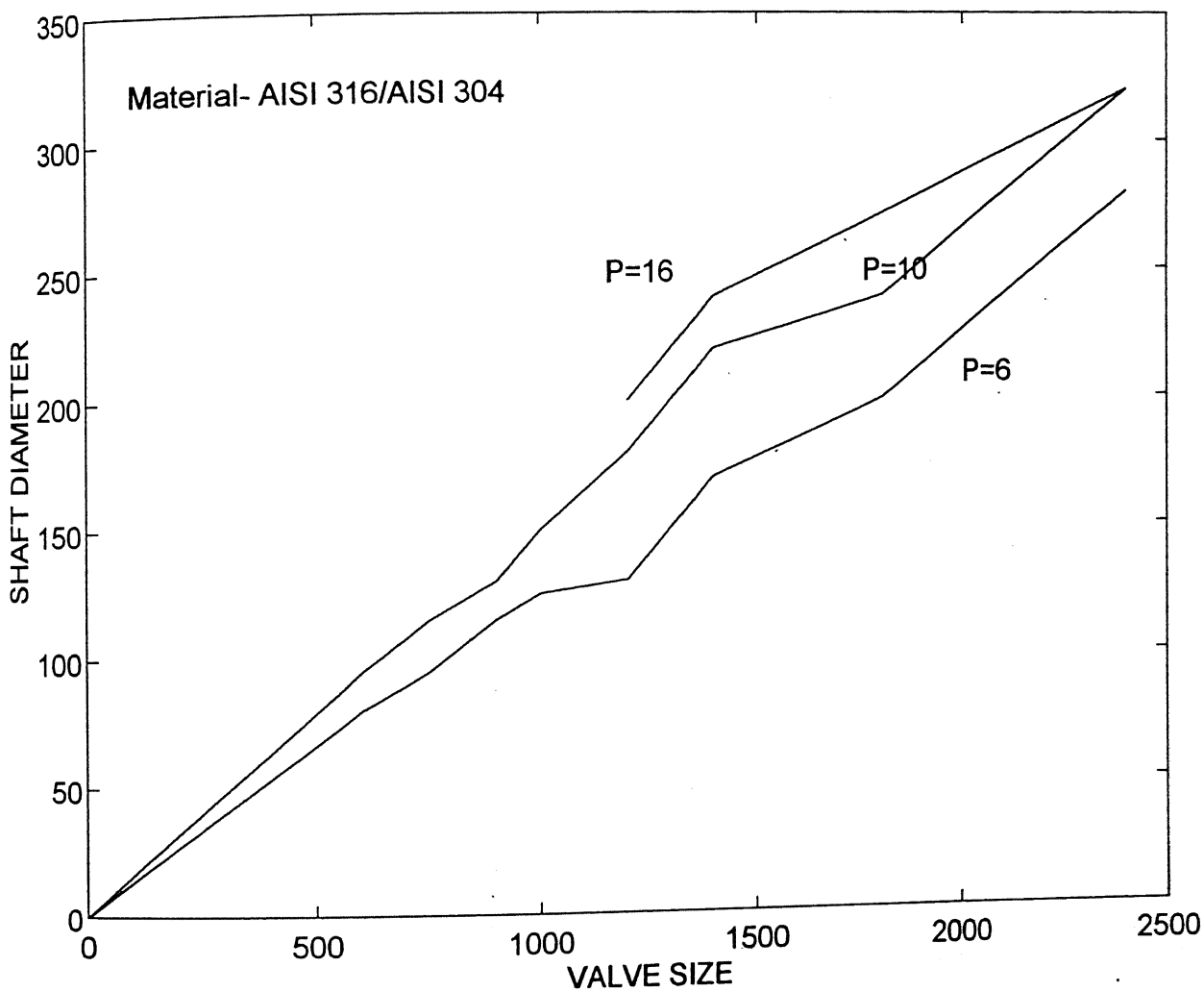


FIGURE 4.2 Relation ship of shaft diameter to valve disc at different pressure.  
( MATERIAL- AISI 316 / AISI 304 )

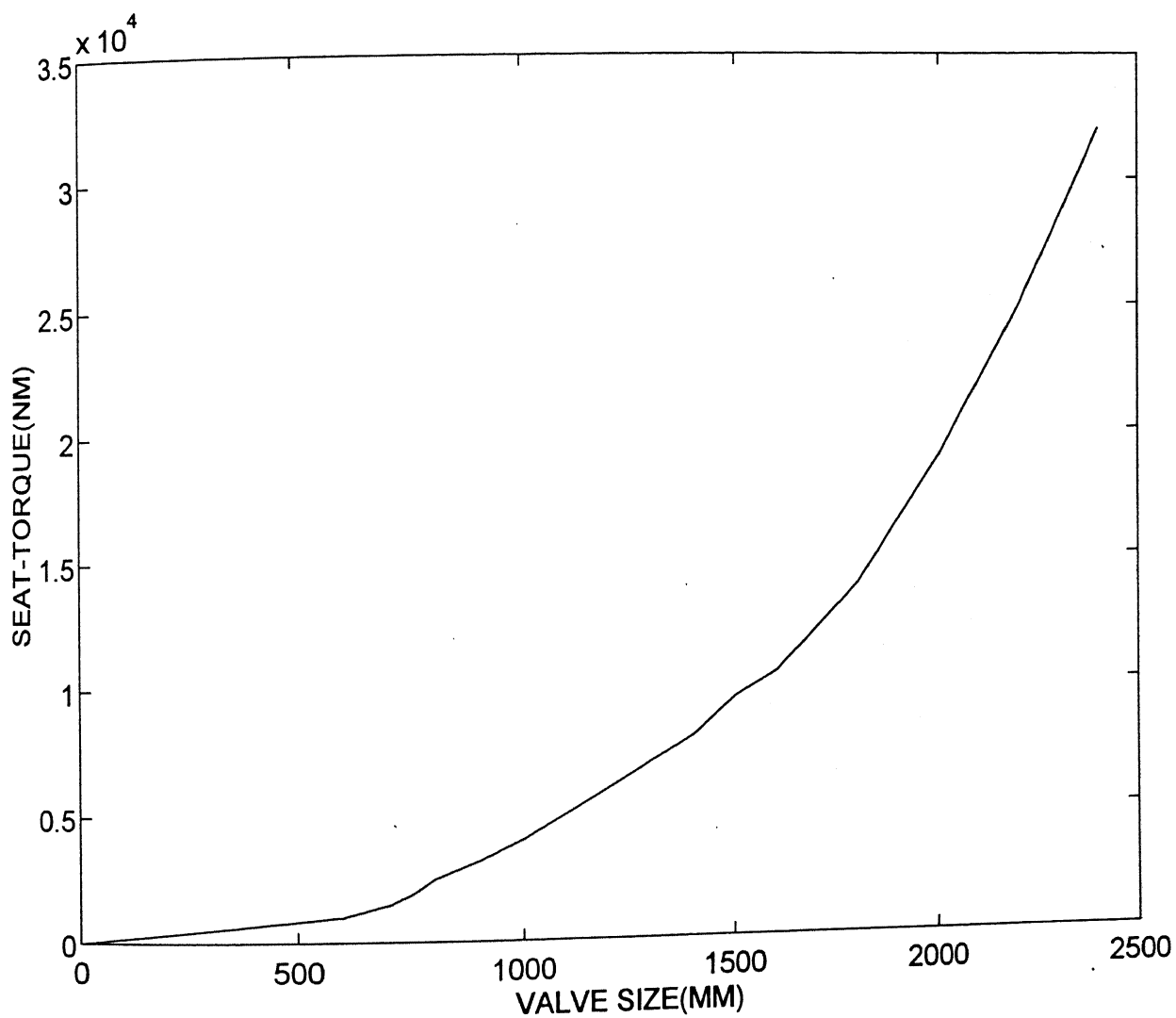


FIGURE 4.3 Relationship of seat torque to valve disc diameter.

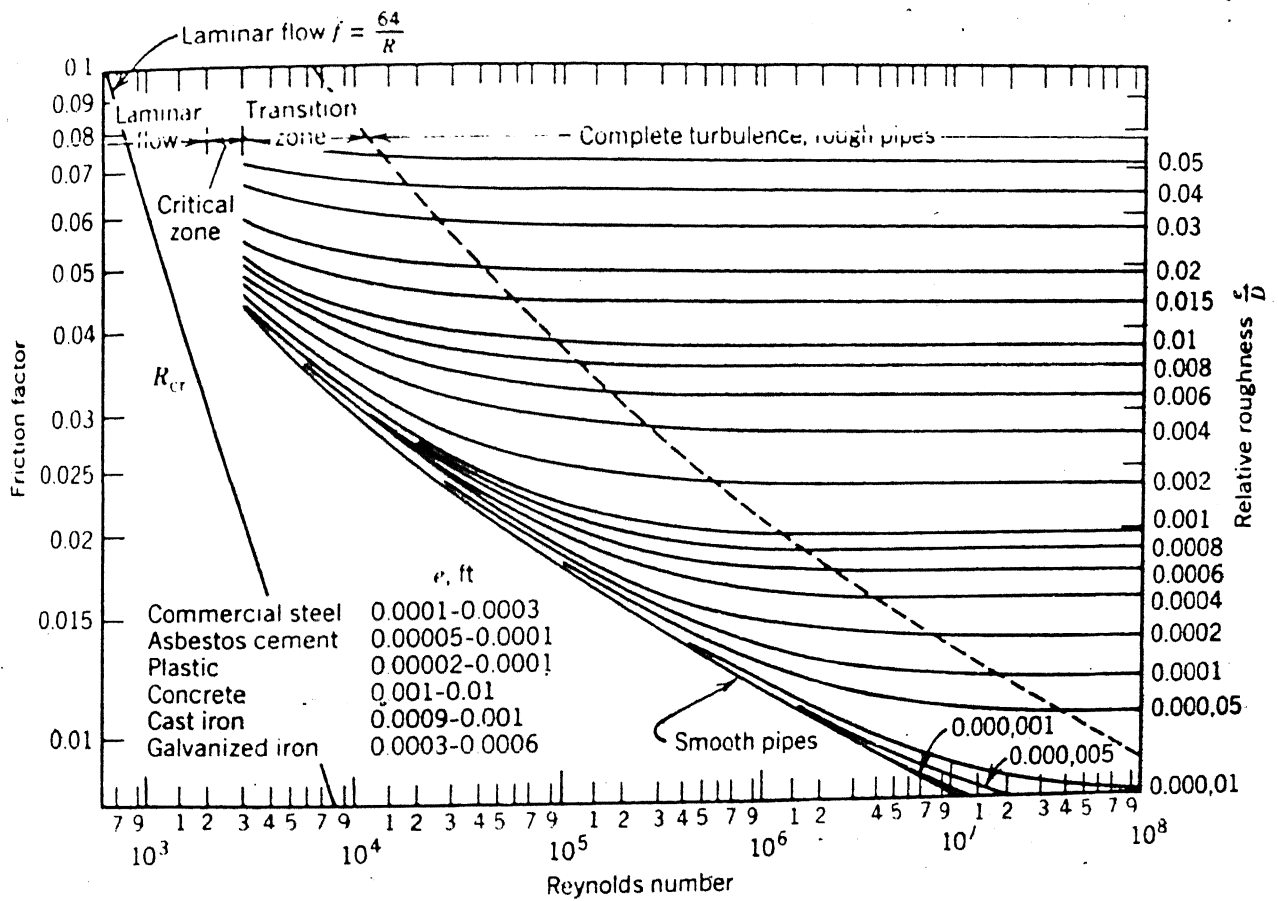


Figure 4.4 Moody chart

## **4.6 DESIGN ALGORITHMS FOR PARTS / STRESS ANALYSIS**

Design algorithms for various parts / stress analysis of butterfly valve is shown below step by step:-

### **4.6.1 CALCULATION OF DISC THICKNESS**

Interact with users to select material as displayed on the screen.

Input design factor of safety.

Calculate thickness and maximum deflection from equation( 3.1), and display the results on the screen.

Display sectional views and results in C-graphic mode.

### **4.6.2 STRESS ANALYSIS OF DISC**

Design disc of lens shape .

Carry out stress analysis of disc from equation (3.2 ).

Display shape of designed disc with results in graphic mode.

If stress exceeds the design stress display warning message.

### **4.6.3 BODY WALL THICKNESS**

Interact with users to select material as displayed on the screen.

Input design factor of safety.

Calculate wall thickness from equation (3.3) and display results on screen.

Display sectional views and results on screen in graphic mode.

### **4.6.4 CALCULATION OF SHAFT DIAMETER , SEAT TORQUE, VALVE**

#### **OFFSET AND TOTAL TORQUE ACTING ON SHAFT**

Calculate shaft diameter as per valve size from ADAM'S CHART expressed as polynomial function .

Calculate seat torque as per valve size from ADAM'S CHART expressed a polynomial function.

Calculate valve offset as per valve size from ADAM'S CHART expressed as polynomial function.

Calculate bearing torque, offset torque from equation( 3.4), and the total torque acting on shaft.

Total torque = Seat torque + bearing torque + offset torque.

Display results.

Display sectional view of shaft with results in graphic mode.

#### 4.6.5 DESIGN OF COLLARED BRONZE BEARING

Interact with users to select material as displayed on the screen.

Input design factor of safety.

Calculate dimensions of bearing from equation (3.6) and display results

Display sectional view of designed bearing along with results in graphic mode.

#### 4.6.6 STRESS ANALYSIS OF SHAFT

Calculate stresses developed on the shaft due to combined bending and torsion effect from equation (3.6)..

If stresses developed in the shaft is more than design stress, display warning message on the screen.

display results on the screen.

#### 4.6.7 DESIGN OF SHAFT KEY / STRESS ANALYSIS

Interact with users to select material as displayed on the screen.

Input design factor of safety.

Select numbers of keys required.

Calculate dimensions of key from equation (3.7).

- Calculate
- a) Surface stress developed in shaft.
  - b) Surface stress developed in hub.
  - c) Induced stresses.

Display warning if stresses developed in shaft exceeds the design stress.

Display sectional view along with results in graphic mode.

#### 4.6.8 DESIGN OF SPLIT THRUST RING / STRESS ANALYSIS

Interact with users to select material as displayed on the screen.

Input design factor of safety.

Calculate dimensions from equation (3.8).

From equation (3.8), find

- a) Bearing stresses.
- b) Bending stresses.

If stresses in shaft exceeds the design stress display warning message.

Display sectional views along with results in graphic mode.

#### 4.6.9 DESIGN OF LOCKING CAP

Interact with users to select material as displayed on the screen.

.Input design factor of safety.

Calculate dimensions of locking cap from equation ( 3.9a ).

#### 4.6.10 DESIGN OF BOLTS FOR LOCKING CAP

a Interact with users to select material as displayed on the screen.

b) Input design factor of safety.

c) Select numbers of bolts.

Calculate core area and core diameter of bolts from equation ( 3.9b ).

Display sectional view of locking cap along with bolts and results in graphic mode.

#### 4.6.11 VALVE FLANGE STRESS ANALYSIS

.Interact with users to select material as displayed on the screen.

Input design factor of safety.

Input standard flange dimensions as per valve size from I.S : 6392-1971.

Carry out stress analysis from equation ( 3.10 ).

If stresses developed in sections > design stress value, display warning message.

Display sectional view along with results in graphic mode.

#### 4.6.12 FLANGE GASKET DIMENSIONS

Calculate and display dimensions of flange gasket dimensions.

#### 4.6.13 DESIGN OF COVER FOR BODY N.D.E

Interact with users to select material as displayed on the screen.

Input design factor of safety.

Calculate and display dimensions of cover from equation ( 3. 12 ).

#### 4.6.14 SHAFT FLANGE STRESS ANALYSIS

Interact with users to select material as displayed on the screen.

Input design factor of safety.

Input standard flange dimensions as per shaft size from I.S.I specifications IS: 6392-1971.

Carry out stress analysis as per form equation ( 3.11 ).

If stresses developed in sections > design stress value, display warning message.

Display sectional view along with results in graphic mode.

#### 4.6.15 TORQUES AND PRESSURE DROP AT VARIOUS DISC ANGLE

Calculate following variables at various disc angle(0 to 90 degrees).

- a) Head loss factor(K).
- b) Pressure drop
- c) Bearing torques
- d) Offset torques
- e) Hydraulic torque
- f) Torques for closing
- g) Torques for opening.

Display above results in the form of chart on screen.

Display line graph between various disc position and pressure drop.

Display the bar chart between various disc position and pressure drop.

#### 4.6.16 PREPARATION OF SUMMARY OF RESULTS

Open file valve.out and write summary of results.

#### 4.6.17 PREPARATION OF SCRIPT FILE

Open file valve.scr and write script file, which when loaded AUTOCAD prepare final drawing along with bills of materials.

### 4.7 ILLUSTRATIVE DESIGN AND TRIAL RUN

To design a butterfly valve for Hydro-power plant with following specifications:

- |                               |                             |
|-------------------------------|-----------------------------|
| 1) Type of valve              | Butterfly valve.            |
| 2) Maximum flow rate required | 15,000 cubic meters / hour. |
| 3) Minimum flow rate required | 12,000 cubic meters / hour. |
| 4) Total available head       | 100 m.                      |
| 5) Maximum pressure           | 8 bar.                      |
| 6) Diameter of pipe line      | 2000 mm                     |
| 7) Total length of pipe       | 200m.                       |
| 8) Material of pipe           | Concrete.                   |
| 9) Number of bend             | 2.                          |



10) Type of entrance

Dull edge.

Select valve flange dimensions as per IS:6392-1971, Assumption of any unspecified conditions and selection of materials for parts is at designer discretion.

#### 4.7.1 RESULTS:-

The program first does the sizing of valve and the optimum valve size obtained for above conditions is 1587.23 mm, since the flanges are available in the market in discret size as per IS:1703-1968 , we select valve size of 1600 mm for designing its parts.

The out put of the program is stored in a separete file "valve.out" which consist of major input parameters followed by output obtained. The sectional views of parts is obtained in C-Graphic mode, some photographs of the screen output are shown in figure 4.5 to 4.16.

The final drawing along with BILLS OF MATERIAL is in AUTOCAD (figure 4.17 ) The out put of file" valve.out " is shown below:-

#### 4.6.2 INPUT PARAMETERS

|                    |                               |
|--------------------|-------------------------------|
| Disc diameter      | 1600mm                        |
| Operating pressure | 8bar                          |
| Maximum flow rate  | 15,000 m <sup>3</sup> / hour. |
| Minimum flow rate  | 12,000 m <sup>3</sup> / hour  |

#### 4.6.3 OUTPUT DATA

##### VALVE DISC THICKNESS

|                    |                  |
|--------------------|------------------|
| Selected material  | GREY IRON FG 35. |
| Thickness of disc  | 51.78 mm         |
| Maximum deflection | 9.44242e-05 mm   |

##### DISC SHAPE PARAMETERS AND STRESS ANALYSIS

With reference to figure 3.1

|          |               |
|----------|---------------|
| Alpha    | 53.79 degrees |
| Beta     | 58.86 degrees |
| Value of |               |
| R        | 1440.0 mm     |
| E        | 216.0 mm      |

|                          |                |
|--------------------------|----------------|
| C                        | 1120 mm        |
| $S_s$                    | 34.5 m         |
| Stress developed in disc | 96.06 N/sq mm. |

#### BODY WALL THICKNESS

|                   |            |
|-------------------|------------|
| Selected material | FG20       |
| Wall thickness    | 76.51 mm   |
| Outer diameter    | 1676.51 mm |

#### DESIGN OF SHAFT, OFFSET AND TORQUES

|                        |                                |
|------------------------|--------------------------------|
| Material specification | St.ST.B970, 431/S39/ST.ST.410. |
| Shaft diameter         | 164.00 mm                      |
| Offset                 | 5.0mm                          |
| Seat torque            | 10859.68 N-m                   |
| Bearing torque         | 20180.18 N-m                   |
| Offset torque          | 8038.40 N-m                    |
| Toal torque            | 39078.27 N-m                   |

#### DESIGN OF COLLARED BEARING

|                   |                                |
|-------------------|--------------------------------|
| Material          | Steel bushing with light liner |
| Length            | 140.041 mm                     |
| Clearence         | 0.328 mm                       |
| Thickness of bush | 13.42 mm                       |
| Collar diameter   | 196.8 mm                       |

#### STRESS ANALYSIS OF SHAFT

|                           |                            |
|---------------------------|----------------------------|
| Stress developed in shaft | 141.09 N / mm <sup>2</sup> |
|---------------------------|----------------------------|

#### DESIGN OF SUNK KEY OF RECTANGULAR CROSS-SECTION

|                         |          |
|-------------------------|----------|
| Material selected       | I.S C-50 |
| Number of keys selected | 2        |
| Length                  | 265.5 mm |
| Bredth                  | 44.25 mm |
| Height                  | 29.5 mm  |

#### STRESS ANALYSIS OF KEY

|                         |                |
|-------------------------|----------------|
| Surface stress in shaft | 80.68 N /sq mm |
|-------------------------|----------------|

Surface stress in hub 66.54 N /Sq mm

Induced stress 20.28 N/sq mm

#### DESIGN AND STRESS ANALYSIS OF SPLIT THRUST RING

Material specification I.S C-40

Outer diameter 196.79 mm

Inner diameter 147.59 mm

Bredth 8.2 mm

Bearing Stress 42.11 kg /sqcm

Design stress 266.67 kg / sq cm

#### DESIGN OF LOCKING CAP

Material specification I.S 80 /2

d 164.0mm

D1 205.0 mm

D2 492.0 mm

Thickness 1.97 mm

Pitch circle diameter 348.5 mm

#### DESIGN OF BOLTS FOR LOCKING CAP

Number of bolts 6

Core area 786.18 sq mm

Core diameter 31.64 mm

#### BUTTERFLY VALVE FLANGE STRESS ANALYSIS

Material selected 35 Mn 2 Mo28

Stress developed in section A-A 120.03N / sq mm

Stress developed in section B-B 151.14 N /sq mm

Stress developed in section C-C 59.68 N /sq mm

#### DIMENSIONS FOR FLANGE GASKET (SOFT MATERIAL,SOFT METAL OR FLAT METAL TYPE)

Inner diameter 1620.0 mm

Outer diameter 1750.0 mm

Thickness 31.82 mm

#### DESIGN OF COVER FOR BODY NON DRIVING END

Material selected

Thickness of cover(t) 31.82 mm

#### DIMENSIONS FOR GASKET FOR COVER

Gasket inner diameter 196.80 mm

Gasket outer diameter 349.82 mm

#### SHAFT FLANGE STRESS ANALYSIS

Stress developed in section A-A 96.49 N /sq mm

#### PRESSURE DROP AND TORQUES AT VARIOUS DISC POSITIONS

| Angle | K      | Pressure Drop | Bearing Torque | Offset Torque | Hyd Torque | Torque Closing | Torque Opening |
|-------|--------|---------------|----------------|---------------|------------|----------------|----------------|
| 0.0   | 1000.0 | 8.0           | 20170.0        | 8038.4        | 32768.0    | 60976.4        | -4559.6        |
| 10.0  | 211.2  | 4.52          | 11414.9        | 4549.2        | 18544.6    | 34508.8        | -2580.5        |
| 20.0  | 23.5   | 0.50          | 1270.0         | 506.1         | 2063.3     | 3839.4         | -287.1         |
| 30.0  | 7.4    | 0.15          | 398.1          | 158.7         | 646.8      | 1203.6         | -90.0          |
| 40.0  | 4.4    | 0.09          | 239.6          | 95.5          | 389.2      | 724.3          | -54.2          |
| 50.0  | 1.5    | 0.03          | 81.0           | 32.3          | 131.6      | 244.9          | -18.3          |
| 60.0  | 1.0    | 0.02          | 55.7           | 22.2          | 90.5       | 168.4          | -12.6          |
| 70.0  | 0.6    | 0.01          | 30.4           | 12.1          | 49.4       | 92.0           | -6.9           |
| 80.0  | 0.4    | 0.007         | 19.0           | 7.6           | 30.9       | 57.6           | -4.3           |
| 90.0  | 0.2    | 0.005         | 13.1           | 5.2           | 21.2       | 39.5           | -3.0           |

#### 4.8 SUMMARY

In this chapter collection of material data base, and procedure of converting Nomograph, Adams chart, Moody chart into polynomial function was given. The design algorithms for parts and stress analysis are also given, finally an illustrative design along with trial run was discussed.

# CROSS-SECTIONAL VIEW OF BUTTERFLY VALVE

| Sr.No | DESCRIPTION          | MATERIAL                      |
|-------|----------------------|-------------------------------|
| 1.    | COVER FOR BODY N.D.E | C-10                          |
| 2.    | SPLIT THRUST RING    | I.S.C-40                      |
| 3.    | FLANGED BUSH         | STEEL_BUSHING_WITH_LIGHT_L    |
| 4.    | PACKING FOR BUSH     | GRAPHITED ASBESTOS            |
| 5.    | DRIVE SHAFT          | ST.ST.BS970,431/S39/ST.ST.410 |
| 6.    | KEY                  | I.S.C-50                      |
| 7.    | FLANGE               | 35_Mn2Mo28                    |
| 8.    | DOWEL PIN            | ST.ST.BS.970,Gr316S16         |
| 9.    | DISC                 | GREY_IRON_FG_35               |
| 10.   | VALVE BODY           | FG-20                         |
| 11.   | SPACER RING          | M.S                           |
| 12.   | 'U'CUP SEAL          | BRONZE I.S-318 Gr2            |
| 13.   | ADAPTER PLATE        | M.S I.S226 GrFe410S           |

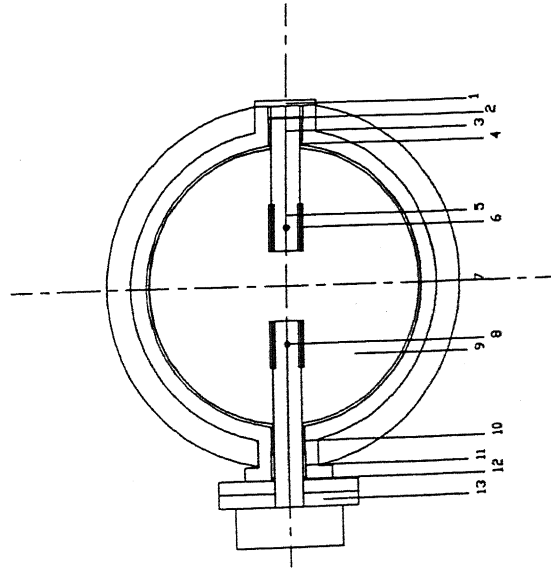


Figure 4.17 Final drawing in AUTOCAD

# CHAPTER-5

## CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER WORK

### 5.1 CONCLUSIONS

The present work is an attempt to develop an interactive design package for butterfly valves. This package will be very useful for irrigation department, Hydro powers plant and industries like Kirloskar Brothers which manufactures these type of valves for commercial purposes. This package can also be used for educational aid since the program is very interactive, easy to operate and display graphic views at every stage of design for easy understanding.

In practice, the entire process of designing a butterfly valves consist of sizing of butterfly valve, which consist of number of iterations and look up charts, and designing its parts with material selection combinations. When this process is carried out manually, it is difficult to explore all the alternative strategies and consumes many man-hours. The job becomes monotonous if iterations is carried out manually, since each iteration is very elaborate and time consuming.

The salient feature of this package is that designer can quickly explore all the alternative design strategies with various material selection combinations and select appropriate design. For this purpose, at every design stage program interact with users and display sectional views of the designed part in graphic mode to give an actual feel of designing.

### 5.2 RECOMMENDATIONS FOR FURTHER WORK

The present version of the program does not deals with the practical Seal design and seats, which is a separate topic in itself, if butterfly valves is to be designed for Petrochemical industries, Oil refineries where highly inflammable, toxic liquids and gases is to handled, and were seepage of fluids can not be tolerated. The design of actuators like hand wheel, electric motors limit switches, torque switches and gear box should be taken into account to avoid loading operation and stopping at intermittent position other than fully open and closed position.

It is hoped that enhanced version of the design package should take into account the above mentioned points.

## REFERENCES

- 1 Zappe R.W, Valve Selection Handbook, Gulf Publishing Company, Houston, London, 1987.
- 2 Schweitzer Philip A, Handbook of Valves, Industrial press INC, 1972.
- 3 Lyons, Jerry L, Lyons' valves' Designers's Handbook, Van Nostrund Reinhold company, 1982
- 4 Askland J.R, Lyons' Encyclopedia of Valves, Van Nostrund Reinhold company. 1975.
- 5 Leonard J.Martins, Practical Seal Design, Marlle Dekker INC, 1984.
- 6 Machine Design Data Handbook (vol 1 & 2 ), Lingaiah K, Narayana Iyengar B.R, Suma Publisher, Bangalore, 1973.
- 7 Shigley, J.E and Mitchell L.D, Mechanical engineering design, Mc Graw-Hill, Singapore(1984).
- 8 Kirloskar Brothers Ltd.
- 9 Crane Technical Paper 410, Crane Co, p.A-23.
- 10 Indian Standards" Penstock and Turbine inlet Butterfly Valves for Hydropower Stations and Systems", part 1 & 2, IS:7326-1974, Indian standard institute, New Delhi.
- 11 Indian Standards" Specification for Steel Pipe Flanges", IS:6391-1971, Indian Standard Institute, New Delhi.
- 13 Robert P. Benedict, Fundamentals of Pipe Flow, A Wiley-Interscience Publications, 1980
- 14 Sam Kannappan P.E, Introduction to Pipe Stress Analysis, A Wiley-Interscience Publications, 1980
- 15 Arthur H.Burr, John B.Cheatham, Mechanical Analysis and Design, Prentice Hall, 1995.
- 16 Timoshenko S, Strength of Materials, D.Van Nostland Company Inc, 1968.
- 17 Paul Tullis.J, Hydraulics of Pipe Lines, John Wiley & Sons, Singapore, 1989.

## USER'S MANUAL

This manual describes the usage of this package and the sequence of events, prompts appearing on the screen. Prompts (:) are self explanatory however, a brief description is given wherever necessary.

Run the program by loading batch file vajra.bat.

(type "vajra" at prompt sign)

Hit any key to flip between text and graphic mode anywhere in the program.

1. Do you want to do sizing of valve ( Y / N )

( Enter yes if you want to do sizing else enter no )

### SIZING OF VALVE

2. a) Input max flow rate required (cubic meter / hour )

b) Input min flow rate required (cubic meter / hour )

c) Input max operating pressure

3.a) Input pipe diameter (in mm)

b) Input total available head (in meter)

c) Select code for type of entrance

(List of type of entrance is displayed on the screen )

d) Enter number of bends

e .Input angle of bends in degrees

f) Input total length of pipe(in meters)

g) Select code for pipe material

(list of material is displayed)

4 Program displays optimum valve size



## DISC THICKNESS/ STRESS ANALYSIS

5. a) Select material code for disc

(List of material along with codes is displayed )

b) Enter factor of safety

6.a) Display sectional view and results in graphic mode.

b) Do you want to redesign the disc(Y/N ) :

## BODY WALL THICKNESS

7. a) Select material code for wall :

(List of material along with codes is displayed )

b) Enter factor of safety :

8. Display sectional view and results in graphic mode.

## SHAFT DIAMETER AND TORQUES

9 a) Select material code for shaft :

(List of material along with codes is displayed )

b) Enter factor of safety :

10. Display sectional view and results in graphic mode.

## COLLARED BRONZE BEARING

11. a) Select material code for bearing:

(List of material along with codes is displayed )

b) Enter factor of safety :

12. Display sectional view and results in graphic mode.

## STRESS ANALYSIS OF SHAFT

13. Display results.

## DESIGN OF SHAFT KEY / STRESS ANALYSIS

14. a) Select material code for key

(List of material along with codes is displayed )

b) Enter factor of safety

c) Enter numbers of key required

15 Display sectional view and results in graphic mode.

## DESIGN OF SPLIT THRUST RING

16. a) Select material code for split thrust ring

(List of material along with codes is displayed )

b) Enter factor of safety .

17 Display sectional view and results in graphic mode.

#### DESIGN OF LOCKING CAP

18. a) Select material code for locking cap.

(List of material along with codes is displayed )

b) Enter factor of safety :

19. Display sectional view and results in graphic mode.

#### DESIGN OF BOLTS FOR LOCKING CAP

20. a) Select material code for bolts:

(List of material along with codes is displayed )

b) Enter factor of safety :

c) Select numbers of bolts.

21. Display sectional view and results in graphic mode.

#### VALVE FLANGE STRESS ANALYSIS

22. a) Select material code for valve flange:

(List of material along with codes is displayed )

b) Enter factor of safety :

23 Input standard flange dimensions as per valve size from IS: 6391-1971

24. Display sectional view and results in graphic mode.

#### FLANGE GASKET DESIGN

25. a) Select material code for gasket:

(List of material along with codes is displayed )

b) Enter factor of safety :

26. Display sectional view and results in graphic mode.

#### DESIGN OF COVER FOR BODY N.D.E

27. a) Select material code for cover

(List of material along with codes is displayed )

b) Enter factor of safety ~

28 Display sectional view and results in graphic mode.

## SHAFT FLANGE STRESS ANALYSIS

29. a) Select material code for flange:

(List of material along with codes is displayed )

b) Enter factor of safety :

30 Input standard flange dimensions as per valve size from IS:6392-1971.

31 Display sectional view and results in graphic mode.

32 Displays torques and pressure drop at various disc positions.

32 Open "valve.out " file to see summary of results at the end of program.

33 Open AUTOCAD and load script file "draw" , to see final assembled drawing of butterfly valve along with bills of materials.

### DESIGN PROCEDURE FOR PACKAGE AND IMPLEMENTATION

The package BUTTERFLY has been coded in C-Language with an extensive use of C-Graphics and Autocad. The whole program is split up into five files of 800-1000 lines each and their executable files are clubbed into one batch file named BUTTERFLY.BAT for continuity of program and to avoid out of memory problems in computer. Each file in itself contains a main program which then calls users written functions to perform specific task. At every design stage program interact with user and display sectional-views of the part with results in C-Graphics to give an actual feel designing. Finally it draws the assembled view of valve in Autocad along with BILLS OF MATERIAL.

The design algorithm is discussed below

The Batch file BUTTERFLY.BAT contains the following executable files:

- a) Valve1.exe.
- b) Valve2.exe
- c) Valve3.exe.
- d) Valve4.exe.
- e) Valve5.exe.

The program is discussed below file by file.

#### FILE 1 : VALVE 1.C

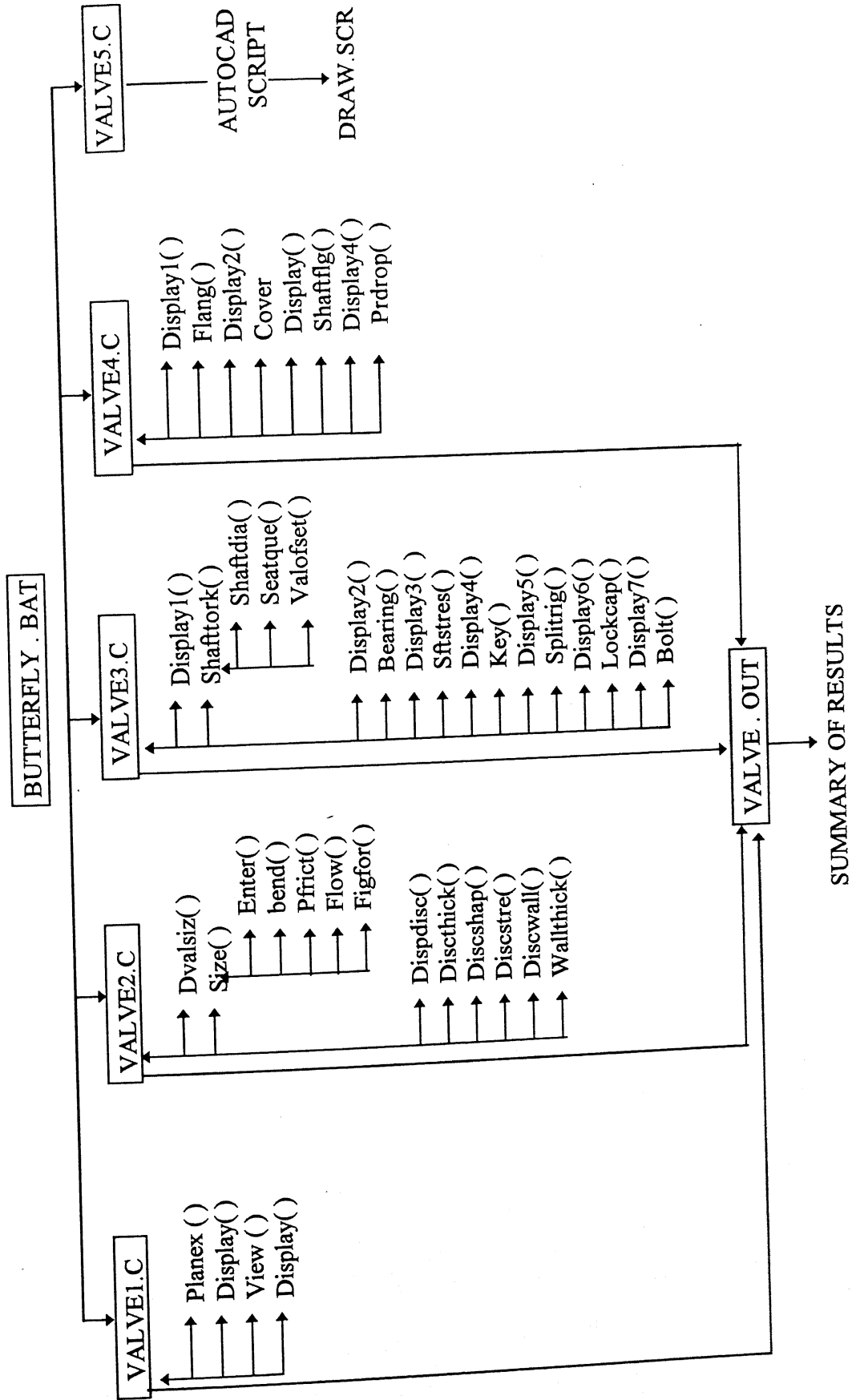
PURPOSE :- 1) To display and animate the main title "COMPUTER AIDED DESIGN OF BUTTERFLY VALVE" in graphics and in text mode.

2) To display sectional view of butterfly valve and to animate the movement of disc in C-Graphic mode to give actual feel to user about valve before design.

## FILE 2: VALVE 2.C

This program interact with users for basic input data, do valve sizing, design parts ,do stress analysis and display them in graphic mode along with results. The main program calls the following functions in steps to perform the task.

| STEPS | FUNCTIONS      | PURPOSE  |
|-------|----------------|--|
| 1.    | dvalsiz( )     | To display title"VALVE SIZING" in graphic mode for 10 sec.               |
| 2.    | size( )        | Do sizing of valve by calling following sub functions:                   |
| 2.a   | enter( )       | Calculate the entrance losses in pipe.                                   |
| 2.b   | bend( )        | Calculate bend losses in pipe.   |
| 2.c   | pfri( )        | Calculate frictional losses in pipe.                                     |
| 2.d   | flow( )        | Calculate optimal control angle.   |
| 2.e   | figfor( )      | Read values of angles from nomograph.                                    |
| 3     | dispdisc( )    | Display"VALVE DISC THICKNESS" in graphic mode for 10 sec.                |
| 4.    | discsthrick( ) | Calculate thickness of disc and display sectional view in graphic mode.  |
| 5.    | discshap( )    | Display shape of disc in graphic mode .                                  |
| 6.    | discstres( )   | Carry out stress analysis of disc.                                       |
| 7.    | dispwall( )    | Display"VALVE BODY THICKNESS" in graphic mode.                           |
| 8.    | wallthick( )   | Calculate thickness of valve and display sectional view in graphic mode. |



### FILE 3: VALVE 3.C

This program interact with user for input data and design parts of valve, do stress analysis and display sectional views of parts in graphic mode. The main program calls the following functions in steps to perform task :

#### STEP FUNCTIONS

#### PURPOSE

|     |             |  |
|-----|-------------|--|
| 1.  | display1( ) | Display "DESIGN AND STRESS ANALYSIS OF VALVE DRIVE SHAFT" in graphic mode. |
| 2.  | shaftork( ) | Calculate total torque acting on shaft by calling following sub-functions: |
| 2a. | shaftdia( ) | Read shaft diameter as per valve size from ADAM'S CHART.                   |
| 2b. | seatque( )  | Read seat torque as per valve size from ADAM'S CHART                       |
| 2c. | valofset( ) | Read valve offset as per valve size from ADAM'S CHART                      |

#### STEP

#### FUNCTION

#### PURPOSE

|    |             |  |
|----|-------------|--|
| 3. | display2( ) | Display "DESIGN OF JOURNAL BEARING" in graphic mode.                   |
| 4. | bearing( )  | Design bearing and display sectional view in graphic mode.             |
| 5. | display3( ) | Display "DRIVE SHAFT STRESS ANALYSIS IN GRAPHIC MODE" in graphic mode. |
| 6. | sftstres( ) | Do stress analysis of shaft for combined bending and torsion.          |

|     |              |  |
|-----|--------------|--|
| 7.  | display4( )  | Display"DESIGN OF SUNK KEY OF RECTANGULAR SECTION".                              |
| 8.  | key( )       | Design key,carry out stress analysis and display sectional view in graphic mode. |
| 9.  | display5( )  | Display "DESIGN OF SPLIT THRUST RING".in graphic mode.                           |
| 10. | splitrig( )  | Design split thrust ring and display sectional view in graphic mode.             |
| 11. | display6.( ) | Display"DESIGN OF LOCKING CAP".  |
| 12. | lockcap( )   | Design locking cap and display sectional view in graphic mode.                   |
| 13. | display7.( ) | Display"DESIGN OF BOLTS".  |
| 14. | bolt( )      | Design bolt for locking cap.   |

#### FILE 4:-VALVE 4.C

This program carry out stress analysis of valve/shaft flange,calculate K-factor,presure drop,hydraulic torque ,torque for closing, torque for opening etc at various disc position and display the graph between pressure drop and disc angle in C-Graphics.It call the following function to perform the task.

| STEP | FUNCTIONS    | PURPOSE   |
|------|--------------|---|
| 1.   | display1 ( ) | Display"VALVE FLANGE STRESS ANALYSIS" in graphic mode.                                |
| 2.   | flang( )     | Carry out stress analysis of valve flange and display sectional view in graphic mode. |
| 3.   | display2( )  | display"COVER FOR N.D.E".   |



| STEP | FUNCTIONS    | PURPOSE   |
|------|--------------|---|
| 4.   | cover( )     | Design cover for N.D.E.   |
| 5.   | display3 ( ) | Display"SHAFT FLANG STRESS ANALYSIS".   |
| 6.   | shaftflg( )  | Carry out stress analysis for shaft flange.   |
| 7.   | display4( )  | Display"PRESSURE DROP Vs DISC ANGLE".   |
| 8.   | prdrop( )    | a.)Calculate K,presure drop,total torque,hydraulic torque,torque for closing,torque for opening at various disc position.<br>b)Display line graph between disc angle and pressure drop.<br>c) Display bar graph between disc angle and pressure drop in C-Graphics. |

#### FILE 5: VALVE 5.C

PURPOSE: This program read design data from the first four file and make script file "DRAW.SCR" for Autocad.Loading "DRAW.SCR" in Autocad draws final assembled drawing of butterfly valve along with BILLS OF MATERIAL.

#### FILE: VALVE.OUT

PURPOSE: This file contains the summary of results of final design of butterfly valve,which can be seen on terminal at any time.

TABLE - 1

## CHART OF OFFSET FOR VARIOUS SIZES OF BUTTERFLY VALVES

| SR.NO. | VALVE SIZE (M M) | OFF-SET (M M) |
|--------|------------------|---------------|
| 1)     | 450 - 1000       | 04            |
| 2)     | 1200 -1800       | 05            |
| 3)     | 2400             | 06            |

TABLE -2 SEAT TORQUE (NM)

| SIZE<br>MM | SEAT TORQUE (NM) |       |        |        |        |
|------------|------------------|-------|--------|--------|--------|
|            | 2.5 BAR          | 6 BAR | 10 BAR | 16 BAR | 25 BAR |
| 600        | --               | 1000  | 1000   | 1000   | 1000   |
| 700        | --               | 1500  | 1500   | 1500   | 1500   |
| 750        | --               | 1900  | 1900   | 1900   | 1900   |
| 800        | --               | 2500  | 2500   | 2500   | 2500   |
| 900        | --               | 3200  | 3200   | 3200   | ---    |
| 1000       | --               | 4000  | 4000   | 4000   | ---    |
| 1100       | --               | 5000  | 5000   | 5000   | ---    |
| 1200       | 6000             | 6000  | 6000   | 6000   | ---    |
| 1300       | 7000             | 7000  | 7000   | ---    | ---    |
| 1400       | 8000             | 8000  | 8000   | ---    | ---    |
| 1500       | 9500             | 9500  | 9500   | ---    | ---    |
| 1600       | 10500            | 10500 | 10500  | ----   | ----   |
| 1800       | 14000            | 14000 | -----  | -----  | -----  |
| 2000       | 19000            | 19000 | -----  | -----  | -----  |
| 2200       | 25000            | 25000 | -----  | -----  | -----  |
| 2400       | 32000            | 32000 | -----  | -----  | -----  |

NOTE : Above Torque Values are subtracted from k138 chart of

ADAMS

TABLE 2.1 SHAFT DIA.

MATERIAL -ST.ST.BS 970 ,431 S 29/ ST.ST.410 HEAT TREATED

| VALVE SIZE<br>MM | SHAFT DIA. (mm) |        |        |
|------------------|-----------------|--------|--------|
|                  | 6 BAR           | 10 BAR | 16 BAR |
| 600              | 60              | 80     | --     |
| 750              | 80              | 80     | --     |
| 900              | 80              | 95     | --     |
| 1000             | 95              | --     | --     |
| 1200             | 115             | 130    | 150    |
| 1400             | --              | 150    | 180    |
| 1800             | 150             | 180    | 220    |
| 2400             | 200             | 240    | --     |

TABLE 2.2 SHAFT DIA.

MATERIAL - AISI 316/AISI 304

| VALVE SIZE<br>MM | SHAFT DIA. (mm) |        |        |
|------------------|-----------------|--------|--------|
|                  | 6 BAR           | 10 BAR | 16 BAR |
| 600              | 80              | 95     | --     |
| 750              | 95              | 115    | --     |
| 900              | 115             | 130    | --     |
| 1000             | 115             | --     | --     |
| 1200             | 130             | 180    | 200    |
| 1400             | --              | 220    | 240    |
| 1800             | 200             | 240    | 320    |

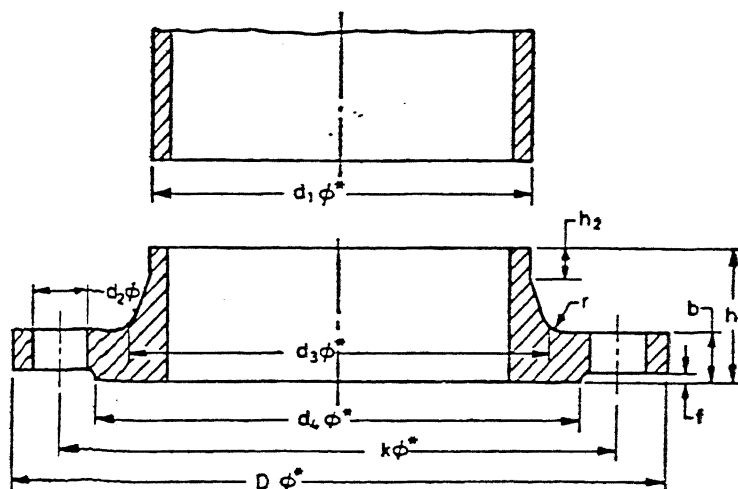
## FOR VALVE FLANGE

TABLE 16 WELDING NECK FLANGES

(Clauses 4.1 and 5.1)

Nominal pressure 1.6 N/mm<sup>2</sup>.

All dimensions in millimetres.



\*These dimensions are not to scale.

| NOM<br>SIZE | PIPE<br>o. d.<br>$d_1$ | FLANGE |     |       | RAISED FACE |     | BOLT-<br>ING | DRILLING |       |      | $d_3$ |
|-------------|------------------------|--------|-----|-------|-------------|-----|--------------|----------|-------|------|-------|
|             |                        | $D$    | $b$ | $h_1$ | $d_4$       | $f$ |              | No.      | $d_2$ | $k$  |       |
| 10          | 17.2                   | 90     | 14  | 35    | 40          | 2   | M12          | 4        | 14    | 60   | 28    |
| 15          | 21.3                   | 95     | 14  | 35    | 45          | 2   | M12          | 4        | 14    | 65   | 32    |
| 20          | 26.9                   | 105    | 16  | 38    | 58          | 2   | M12          | 4        | 14    | 75   | 40    |
| 25          | 33.7                   | 115    | 16  | 38    | 68          | 2   | M12          | 4        | 14    | 85   | 45    |
| 32          | 42.4                   | 140    | 16  | 40    | 78          | 2   | M16          | 4        | 18    | 100  | 56    |
| 40          | 48.3                   | 150    | 16  | 42    | 88          | 3   | M16          | 4        | 18    | 110  | 64    |
| 50          | 60.3                   | 165    | 18  | 45    | 102         | 3   | M16          | 4        | 18    | 125  | 75    |
| 65          | 76.1                   | 185    | 18  | 45    | 122         | 3   | M16          | 4        | 18    | 145  | 90    |
| 80          | 88.9                   | 200    | 20  | 50    | 138         | 3   | M16          | 8        | 18    | 160  | 105   |
| 100         | 114.3                  | 220    | 20  | 52    | 158         | 3   | M16          | 8        | 18    | 180  | 131   |
| 125         | 139.7                  | 250    | 22  | 55    | 188         | 3   | M16          | 8        | 18    | 210  | 156   |
| 150         | 168.3                  | 285    | 22  | 55    | 212         | 3   | M20          | 8        | 22    | 240  | 184   |
| 175         | 193.7                  | 315    | 24  | 60    | 242         | 3   | M20          | 8        | 22    | 270  | 210   |
| 200         | 219.1                  | 340    | 24  | 62    | 268         | 3   | M20          | 12       | 22    | 295  | 235   |
| 250         | 273                    | 405    | 26  | 70    | 320         | 3   | M24          | 12       | 26    | 355  | 292   |
| 300         | 323.9                  | 460    | 28  | 78    | 378         | 4   | M24          | 12       | 26    | 410  | 344   |
| 350         | 355.6                  | 520    | 30  | 82    | 438         | 4   | M24          | 16       | 26    | 470  | 390   |
| 400         | 406.4                  | 580    | 32  | 85    | 490         | 4   | M27          | 16       | 30    | 525  | 445   |
| 500         | 508                    | 715    | 34  | 90    | 610         | 4   | M30          | 20       | 33    | 650  | 548   |
| 600         | 609.6                  | 840    | 36  | 95    | 725         | 5   | M33          | 20       | 36    | 770  | 652   |
| 700         | 711.2                  | 910    | 36  | 100   | 795         | 5   | M33          | 24       | 36    | 840  | 755   |
| 800         | 812.8                  | 1025   | 38  | 105   | 900         | 5   | M36          | 24       | 39    | 950  | 855   |
| 900         | 914.4                  | 1125   | 40  | 110   | 1000        | 5   | M36          | 28       | 39    | 1050 | 955   |
| 1000        | 1016                   | 1255   | 42  | 120   | 1115        | 5   | M39          | 28       | 42    | 1170 | 1058  |
| 1200        | 1220                   | 1485   | 48  | 130   | 1330        | 5   | M45          | 32       | 48    | 1390 | 1262  |
| 1400        | 1420                   | 1685   | 52  | 145   | 1530        | 5   | M45          | 36       | 48    | 1590 | 1465  |
| 1600        | 1620                   | 1930   | 58  | 160   | 1750        | 5   | M52          | 40       | 56    | 1820 | 1668  |
| 1800        | 1820                   | 2130   | 62  | 170   | 1950        | 5   | M52          | 44       | 56    | 2020 | 1870  |
| 2000        | 2020                   | 2345   | 66  | 180   | 2150        | 5   | M56          | 48       | 62    | 2230 | 2072  |

# FOR SHAFT FLANGE

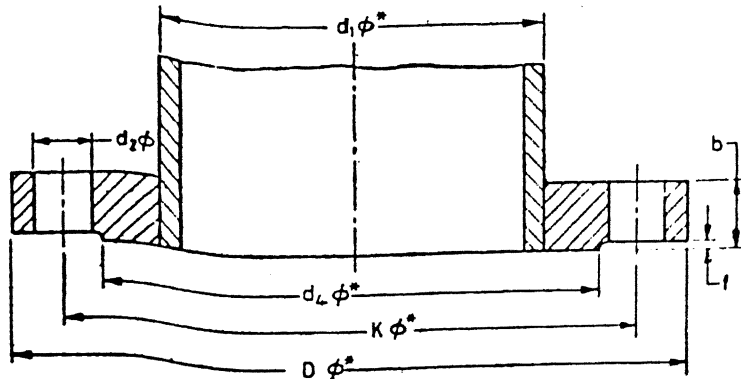
IS : 6392 - 1971

TABLE 17 PLATE FLANGES FOR WELDING

(Clauses 4.1 and 5.1)

Nominal pressure 1.6 N/mm<sup>2</sup>.

All dimensions in millimetres.



\*These dimensions are not to scale.

| Nom<br>Size | PIPE<br>o. d.<br>$d_1$ | FLANGE |     | RAISED FACE |     | BOLT-<br>ING | DRILLING |       |       |
|-------------|------------------------|--------|-----|-------------|-----|--------------|----------|-------|-------|
|             |                        | $D$    | $b$ | $d_4$       | $f$ |              | No.      | $d_2$ | $k$   |
| 10          | 17.2                   | 90     | 14  | 40          | 2   | M12          | 4        | 14    | 60    |
| 15          | 21.3                   | 95     | 14  | 45          | 2   | M12          | 4        | 14    | 65    |
| 20          | 26.9                   | 105    | 16  | 58          | 2   | M12          | 4        | 14    | 75    |
| 25          | 33.7                   | 115    | 16  | 68          | 2   | M12          | 4        | 14    | 85    |
| 32          | 42.4                   | 140    | 16  | 78          | 2   | M16          | 4        | 18    | 100   |
| 40          | 48.3                   | 150    | 16  | 88          | 3   | M16          | 4        | 18    | 110   |
| 50          | 60.3                   | 165    | 18  | 102         | 3   | M16          | 4        | 18    | 125   |
| 65          | 76.1                   | 185    | 18  | 122         | 3   | M16          | 4        | 18    | 145   |
| 80          | 88.9                   | 200    | 20  | 138         | 3   | M16          | 8        | 18    | 160   |
| 100         | 114.3                  | 220    | 20  | 158         | 3   | M16          | 8        | 18    | 180   |
| 125         | 139.7                  | 250    | 22  | 188         | 3   | M16          | 8        | 18    | 210   |
| 150         | 168.3                  | 285    | 22  | 212         | 3   | M20          | 8        | 22    | 240   |
| 175         | 193.7                  | 315    | 24  | 242         | 3   | M20          | 8        | 22    | 270   |
| 200         | 219.1                  | 340    | 24  | 268         | 3   | M20          | 12       | 22    | 295   |
| 250         | 273                    | 405    | 26  | 320         | 3   | M24          | 12       | 26    | 375   |
| 300         | 323.9                  | 460    | 28  | 378         | 4   | M24          | 12       | 26    | 410   |
| 350         | 355.6                  | 520    | 32  | 438         | 4   | M24          | 16       | 26    | 470   |
| 400         | 406.4                  | 580    | 36  | 490         | 4   | M27          | 16       | 30    | 525   |
| 500         | 508                    | 715    | 44  | 610         | 4   | M30          | 20       | 33    | 650   |
| 600         | 609.6                  | 840    | 52  | 725         | 5   | M33          | 20       | 36    | 770   |
| 700         | 711.2                  | 910    | 58  | 795         | 5   | M33          | 24       | 36    | 810   |
| 800         | 812.8                  | 1 025  | 64  | 900         | 5   | M36          | 24       | 39    | 950   |
| 900         | 914.4                  | 1 125  | 72  | 1 000       | 5   | M36          | 28       | 39    | 1 050 |
| 1 000       | 1 016                  | 1 255  | 78  | 1 115       | 5   | M39          | 28       | 42    | 1 170 |
| 1 200       | 1 220                  | 1 485  | 94  | 1 330       | 5   | M45          | 32       | 48    | 1 390 |